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Industrial Reuse and Recycle of Wastewaters - Literature Review

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Literature Review

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A review of the literature on reuse/recycle of wastewaters by industry is presented in this report. The principal time period reviewed was 1967-1978. An attempt was made to include the most prominent references for nine different industrial categories. In addition, the report includes sections on industrial use of municipal wastewater, reclamation processes, and economics of water reuse/recycle.

It must be remembered, however, that while reuse possibilities are numerous and easy to propose, each reuse case is different to some extent. In all cases, the decision on what water can be recycled is not casual but must be based on careful evaluations of process requirements.

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INDUSTRIAL REUSE AND RECYCLE OF WASTEWATERS

LITERATURE REVIEW

by

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the Nation'a land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized. EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in ground water; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control, or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

In order to control or abate pollution from industrial sources, it has become apparent that in-plant controls will be necessary. The reuse/recycle of process and/or total plant wastewaters must be an integral part of any in-plant control program. Reuse/recycle technology and systems imployed in one industry may have applications in another industry; therefore, a comprehensive review of information related to industrial reuse/recycle of wastewaters should prove beneficial to anyone interested in industrial pollution control. This report reviews prominent literature published primarily during the 1967-1978 period on the reuse/recycle of wastewaters for nine different industrial categories. In addition, literature on economics of wastewater reuse/recycle and processes necessary for reuse/recycle is included. It is anticipated that this report will provide a digest of present reuse/recycle practices by industry.

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ABSTRACT

The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) requires industry to achieve the goal of zero discharge by 1985. In order for industry to reach this goal, reuse/recycle of treated wastewaters will be necessary.

A review of the literature on reuse/recycle of wastewaters by industry is presented in this report. The principal time period reviewed was 1967-1978. The majority of the references were located either in Water Resources Information Center Bibliographies on Water Reuse or the Journal Water Pollution Control Federation Annual Literature Review. A total of 912 references are cited. Since the literature on reuse/recycle is voluminous, it was impossible to include all references on the subject; however, an attempt was made to include the most prominent for nine different industrial categories. In addition, the report includes sections on industrial use of municipal wastewater, reclamation processes, and economics of water reuse/recycle.

There is ample evidence in the literature to suggest that the reuse/recycle of wastewaters by industry is feasible. Successful applications of reuse/recycle technology have been claimed at numerous industrial installations.

It must be remembered, however, that while reuse possibilities are numerous and easy to propose, each reuse case is different to some extent. In all cases, the decision on what water can be recycled is not casual but must be based on careful evaluations of process requirements.

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SECTION 1

INTRODUCTION

The Federal Water Pollution Act (FWPCA) Amendments of 1972 (PL 92-500) comprise far-reaching legislation requiring major responses from industry (1). Industry is now faced with the problem of achieving zero discharge by 1985 (2). This has led to renewed effort to develop water reuse systems for industrial processing. Reuse of treated wastewaters by industry will be required if the 1985 goal of zero discharge is to be met (3). The relationship of PL 92-500 and the implementation of wastewater reuse projects was reviewed by Herson (4).

The Environmental Protection Agency (EPA) views closed-cycle water systems (zero discharge) as an ultimate goal for industrial plants to control water pollution (5). Although total reuse may be presently unattractive from an economic standpoint, future disposal requirements may increase the worth of waters now discarded. Accordingly, new plants must locate water-use and distribution systems in a manner conducive to conversion to closed-cycle systems, and older facilities must incorporate reuse/recycle facilities in new construction projects. Milligan (6) noted that maximum reuse of wastewater must become a normal operating practice if the established goals for the clean-up and elimination of pollutants discharged into navigable waters are to be achieved.

Zero discharge refers to a goal for water-use systems in which all wastes are resources which can be used (7). It is based on a concept of finite resources. Steps in establishing a zero-discharge strategy are: 1) inventorying waste consumption item by item and listing positive means to be adopted to limit consumption to minimum levels required by each process stage, 2) defining qualities of water required, and 3) establishing treatment levels for recycle of water.

Professional people in the field of industrial pollution control have said for many years that the ultimate goal should be elimination of effluent discharges to the maximum possible extent (8). Reduction of waste volumes by good housekeeping, conservation, and reuse is the first step recommended in any engineering text on pollution control. Angelbect et al. (9) foresees total water recirculation with possible by-product recovery to be the most immediate solution to the wastewater problem.

Train (10) reviewed EPA activities in the areas of wastewater treatment and water reuse along with future challenges in these areas. The Agency has put strong emphasis on research and development associated with water reuse.

Norman (11) examined the reasons for reuse of water. Three motives--scarcity of resources, environmental constraints, and economics--are shown to be the principal ones. The prime reason can differ for different locations. Modes of water reuse are described. The equipment and processes utilized to prepare the water for the various usages vary with quality and environmental requirements. Some of the problems encountered in water reuse and future developments to overcome these are described.

Othmer (12) observed that the ancient philosophy of waste disposal by dilution must give way to optimizing primary, secondary, and tertiary treatments for maximum product recovery and water recycling.

Water reuse is becoming an increasingly attractive solution to industry (13). New, stricter pollution control standards require large expenditures to clean industrial waste streams. In many cases, only a small additional cost would bring these same streams to reusable water quality. In addition, the costs of providing fresh water from local supplies is increasing. Since many industrial waste streams are spent washwaters, it is often possible to recover by-products of value from the wastes. All of these factors combine to make water reuse an increasingly attractive economic alternative.

The practice of water reuse can be divided into sequential reuse and recirculation (14). Sequential reuse is the practice of using a given water stream for two or more processes or operations before final treatment or disposal--i.e., to use the effluent of one process as the input to another. Treatment may or may not occur between each process or operation. Recirculation is the practice of recycling the water within a unit process or group of processes. A combination of these practices will be required for an optimum reuse scheme. For purposes of definition, reuse is defined as the utilization of water that has been used previously for another purpose; whereas recycle is the reuse of the same water one or more times for the same purpose (5).

Dugan and McGaufey (15) stated that reclamation and reuse of wastewater has been inhibited by: 1) confusion concerning objectives of water reuse, 2) need for relating treatment effort to the use, 3) guidelines regarding effluent discharge, and 4) serious consideration of energy conservation versus water reuse. A review of the factors involved in the reuse of water was presented. Suhr (16) discussed the concept of wastewater reclamation. Pollution abatement is probably the most important aspect of wastewater reclamation. Reclaimed waters may be used in agriculture, industrial processes, groundwater recharge or domestic recycling.

In the past, most water reusers were primarily motivated by either the lack of adequate water sources or by higher pollution standards (17). As wastewater treatment requirements have become more uniform and stringent throughout the nation and the costs of meeting these requirements have increased, the management of water resources has become more critical, and the reuse of wastewaters has become more attractive. At the present time, the reuse practice is not limited to any particular industry; but major water users, such as power, steel, petroleum, chemicals, and pulp and paper industries, have been involved in wastewater reuse for varied purposes such as cooling, processing, boiler feed, washing, and others.

The practice of treating wastewater to obtain compliance with discharge regulations may often produce a water of sufficiently high quality to allow its reuse within the plant (18); however, once this is recognized, the entire subject of reusing water in industrial process facilities can be viewed from a somewhat different perspective. The major concern is now shifted from the environment to one of proper water management, and an intelligent evaluation may uncover technically and economically better methods to achieve a total reuse program.

Water reuse is a solution to two major problems associated with this natural resource: water pollution and diminishing new, suitable water supplies (19). The benefits from industrial water conservation and reuse are manifold. Through proper management, all water can be used to the maximum extent before disposal, resulting in a lesser demand from the primary source and releasing to some degree the constraints imposed by the quantity and quality of this source (14). Another benefit would be increased product recovery and more efficient use of raw materials. Minimization of the waste treatment problem would also result from improved control.

The obvious benefit to industry of a closed-cycle water-use system is that the rules cannot change very much and the costs of pollution control can be predicted for a long time in the future (8). Water users would, at the same time, have the maximum practical protection of water quality. The practice of recirculation reduces the overall water volume, reduces the amount of water subjected to pollution, thus reducing the size, and the cost of facilities needed to maneuver and treat the water (20).

There are two basic methods by which recirculation systems are designed and operated (21). Recirculation can be incorporated on each separate process, or all process waters can be combined, treated to the extent necessary, and used as intake water for all processes. The choice usually depends upon the water-use system prior to design of the recirculating system.

The advantages of recycling water are outlined by Cillie and Stander (22). Recycling prevents water pollution, while being an important water augumentation system for producing water conforming to the quality requirements for a wide range of uses and constitutes an economically attractive method of providing new water.

Burnham (23) reviewed design and operating practices for controlling water pollution from waste treatment operations at a minimum cost. The most effective way to eliminate pollution is at the source. Water reuse is a pollution control technique which can provide valuable by-products and an inexpensive source of process water.

Terminal treatment facilities are subject to malfunctions, as are all chemical and mechanical operations (21). These failures can result in little or no treatment, and resulting discharge of contaminant loads equal to that from several days of normal operation can occur in a few hours of down-time. A properly designed recycle system, however, can continue to be operated with no discharges while repairs are accomplished. Reliability of environmental protection is an inherent advantage of a recycle system.

Even in areas of abundant supply, treatment for recycle is often more economical than treatment to meet stringent discharge requirements. Smith (24) reported that wastewater can be reused not only for water savings but also in some cases to effect an energy savings as well. Wagstaffe (25) reports that the shortage of raw materials and energy has provided added incentive to reduce pollution by recovery of wastes for recycling or reuse.

The ability of a plant to produce an effluent which meets current and future EPA guidelines is due in large part to establishment of and adherence to a water management plan which places great emphasis on water reuse and product recovery (26). A water management plan is presented with emphasis on water reuse and product recovery for a paper mill which processes waste scrap paper into paper used in the manufacture of wallboard liner. Operating data are included which illustrate how this plant is able to meet Federal EPA effluent guidelines with minimum end-of-pipe treatment due to an effective water plan.

Benefits accruable to reclamation and reuse include the identifiable economic, ecological, and social impact on receiving waterways because of greatly reduced pollutional loads (16). In addition, other benefits, including reduced cost for development of alternate sources of water supply, maximum development and use of the existing water resource, and the ability to serve more people and industries must be considered. Economic justification of water reclamation and reuse is possible only if all potential benefits are considered. With any industry water management program, the goal must be the development of performance-guaranteed wastewater treatment at best costs (1).

Channabasappa (27) contends that increased industrial water requirements can be met only by in-plant recirculation and reuse. By reuse and recirculation, the total water requirement of industry can be reduced (28). Where cooling is the principal use, substitution of recycle for once-through can reduce the water intake by as much as 90 percent.

Because of the rapid municipal and industrial expansions, one-time use of water has become a luxury that can no longer be afforded (29). Renovation of wastewater for deliberate reuse must be practiced. Water, once used for domestic and industrial purposes, still constitutes a natural resource that can be renovated and reused (16).

It has long been recognized that municipal and industrial wastes may become an important water resource for industry (30). In the past, treated wastewaters have been used primarily as cooling water. However, with the advent of economic demineralization processes, it is possible to consider water reuse for many additional processing requirements. Direct water reuse must be considered as an alternative to development of new water resources (31). A general treatment of direct water reuse and possible applications of reuse were provided.

Because of the convergence of the diminishing supply of water and the demands placed on that supply, the advanced level treatment and reuse of wastewater has gained recognition as a keystone of total water resource management (32). More rigid requirements for wastewater disposal have intensified the reuse of water and the interest in various unit processes that might be utilized for renovating wastewaters to meet effluent and/or reuse criteria.

Recent restrictive regulations and limited fresh-water supplies have emphasized the importance of reusing effluent water (33). Scarcity of fresh water has led some industries to reuse substantial quantities of fresh water for various services, including cooling tower make-up and boiler feed water (34).

Morris (35) and Partridge and Paulson (36) discussed various aspects of the general subject of wastewater renovation and reuse. Singer (37) gave a brief general discussion of reasons for water renovation and reuse, estimating that cities and industries could increase their existing supply of fresh water five times by total renovation and recycling of 80 percent of the water they use. Gallagher (38) discussed the reuse of reclaimed water as a supplement for industrial cooling and process water. Reidinger et al. (30) presented a discussion principally concerned with what might be considered industrial applications for wastewater treatment and reuse.

Industrial wastes often contain toxic chemicals whose disposal into surface waters is objectionable for many reasons (39). On the other hand, certain toxic chemicals, if recovered from industrial waste, bring high economic returns in addition to removing the pollution load from the waste stream. Where the water recovered from these wastes is of good quality, it can be reused, resulting in reduction of waste and costs of treatment. Such reuse of wastewater is often a necessity when the natural water is inadequate to fill increasing needs of expanding populations and industries.

The use of renovated industrial and municipal wastewaters to supplement raw water sources is becoming widely accepted, and in many cases, is being shown to be the water source alternative at least cost (40). The future trend appears to be in favor of increased water reuse because of increasing pollution control standards and raw water costs.

Scherm and Lawson (41) conducted a study with emphasis on tertiary treatment and the feasibility of wastewater renovation for industrial reuse. Fritsche and Schima (42) discussed the reuse of industrial and/or municipal wastewater for industrial water needs. The reuse of industrial wastewater may significantly reduce water consumption requirements.

A great deal of concern has been expressed for the future development of wastewater treatment systems (43). The primary concern is for finding means of reusing treated wastewater instead of merely disposing of it. It is emphasized that any system or method must be cost effective.

Wastewater is reused, principally, for economic reasons (34). Raw water itself, the treating of raw water, and treating wastewater to meet discharge regulations all cost money. Present usage and future predictions of water demands make water resource conservation, renovation, and reuse of wastewater imperative (44).

By the year 2000, the U.S. will need over 1 trillion gallons of water daily (45). With common sense and careful management, availability can be assured through steady attempts to close the loop by recycling or reuse in another function. Heckroth (46) reviewed the overall potential for reuse by industry and found that 20 percent of the industrial water demand could be met by reuse in 1980 and 54 percent by the year 2020. Industries with the greatest potential for reuse are pulp and paper, plastics, meat processing, primary metals, drugs, detergents, food processing, petroleum, and rubber.

The purpose of this report is to present a review of available literature as it pertains to industrial reuse and recycle of wastewaters. Specific topics include: industrial use of municipal wastewaters, reuse and recycle of wastewaters by specific industrial categories, reclamation processes and economics of reuse practices.

SECTION 2

INDUSTRIAL USE OF MUNICIPAL WASTEWATER

Several factors are responsible for increased interest in reusing municipal wastewater during the last few years: 1) in many areas of the country, water is in short supply, 2) advances in wastewater engineering have made possible higher efficiencies in the removal of pollutants from municipal effluent, and 3) concern about the quality of man's environment and the Nation's water resources has been increasing (4).

Gavis (47) evaluated the potential for wastewater reuse through reclamation of effluents from advanced wastewater treatment plants. The potential for reclamation of used municipal and industrial water was discussed. An optimistic view was presented for the growth of the practice of water reuse, concluding that the practice of water reuse will continue to grow with the growth of population and industry in the United States.

Two potential sources from which industrial water needs can be obtained are municipal and industrial wastes (48). Whether it is economical to get additional industrial water by desalination of sewage or industrial wastes or both must be based on: 1) cost and availability of alternate water resources, 2) actual cost of treating wastes by desalination processes, 3) value of by-product recovery, and 4) cost savings accruing from lesser volumes of wastes to be discharged.

Eller et al. (49) discussed industrial water reuse and recycling with particular emphasis placed on the reuse of municipal wastewaters by selected industries. Experience has shown that industrial use of reclaimed sewage effluents can be economical; such sources also have the advantages of constant composition and dependable flow (50).

Garland (51) discussed the potential for development of industrial water supplies from municipal wastewater effluents. He also presented a flowsheet for a typical reclamation plant. Mendia (52) described treatment of the secondary effluent from a municipal wastewater plant to render it suitable for industrial reuse. Janacek (53) discussed the feasibility of utilizing renovated municipal wastewater effluent as makeup for boiler applications.

It is apparent that industry has a relatively large untapped water resource available in reclaimed sewage effluent (54). Examples of industrial use of sewage reclaimed wastewaters were presented. McJunkin (55) reported that reuse of municipal wastewater for industrial supply appears to offer the greatest potential for increasing available water resources.

Many areas with a water shortage have resorted to reuse of treated wastewater effluent in order to augment their water supplies (56). Industries have found that municipal effluent is suitable and less costly than treated potable water for cooling purposes. As the effluent quality improves due to improvements in waste treatment facilities, the effluent becomes suitable for more industrial functions. Weddle et al. (57) reported that renovated municipal wastewater may be used as make-up for cooling towers or as boiler feed water.

Petrasek et al. (58) reviewed industrial water supply problems and requirements. The quality of water required depends on whether it will be used as a coolant or as boiler feed. Tests were performed at a treatment facility on two different treatment sequences: biological-physical and biological-physical-chemical. The authors reported that primary effluents, although not of high quality, have certain applications as cooling waters and in the lumber and metals industries. Activated sludge effluent can be used in the lumber, petroleum, metals, cement, and paper industries. When filtered, this water can be used in finishing and rinsing processes. After activated carbon adsorption, the effluent is considered to be of high quality and can be used for all industries except those requiring potable water.

Train (10) reported that the reuse of municipal wastewater was being practiced on a continuing basis in 358 locations throughout the United States, chiefly in the semi-arid southwestern states. Principal applications include irrigation, landscaping, industrial cooling and processing water utilization, and recreation lake maintenance. He noted that the present reuse of wastewater, however, is small in relation to the amount of municipal wastewater being generated and that expanded practice and continued development of municipal wastewater reclamation is required.

A survey of municipal reuse indicated that 358 locations, mostly in the semi-arid southwest United States, reuse wastewater for such purposes as irrigation, industrial cooling and process water, recreational lakes, and fish propagation (59). Of the total volume of 113 billion gallons per year of reused water, 53.5 billion gallons were used at 14 industrial plants. A list of industrial users of reclaimed municipal wastewaters was prepared by Sawyer (60).

In South Africa, secondary effluents have been reclaimed for industrial and other purposes for some time (61). The reuse of wastewater for industrial purposes is possible at competitive prices and is considered a rational way to deal with increasing water demands. Hart and Henson (62) reported on South African experience using municipal wastewater in various industries.

Ikehata (63) discussed the reuse of municipal wastewater in Japan. Water reuse has been limited to industrial water. Techniques for the reclamation of municipal wastewater for reuse were reviewed. Kubo (64) reported that steel mills, metal-working, and chemical industries, using water for cooling and washing, have been the principal effluent users.

The largest use of water in industry is for cooling and boiler feed (65). The author projected that municipal effluent would be the most logical source of cooling water needed to supply the increasing power demand for north-central Texas. Municipal wastewater and industrial waste streams have been reported as potential cooling water sources, provided the contaminants were properly defined when evaluating suitability of a water for cooling purposes (66).

Mckee (67) surveyed the potential use of reclaimed wastewaters in north central Texas and determined that the largest potential market of renovated municipal effluent was the steam-electric power industry that required make-up water for cooling towers. By reuse of wastewaters for cooling purposes, the power industry could readily be able to meet the future generating capacity requirements for the area.

Van Eeden (68) described a cooling system in South Africa that conserved water for operating at higher levels of dissolved solids and restricted blowdown. The cooling water is concentrated six to eight times, mixed with demineralizer brines, and used for conveying fuel ash. Treated sewage effluents are used as make-up water.

Francis et al. (69) reported on the use of treated sewage effluents for cooling and quenching applications in cement work and cooling purposes in power stations, incinerators, and engines. Savings amounting to 82 percent of the cost of purchasing high-grade water have been realized.

Folster and Barkley (70) described wastewater reuse practices for west Texas, New Mexico, and Arizona. Municipal wastewater from Amarillo, Texas, is being used by the Southwestern Public Service Company for its steam-powered electric generating plants and by Texaco for cooling and boiler water make-up. The El Paso Products Company in Odessa, Texas, uses treated municipal effluent in its chemical manufacturing operations. Cosden Oil and Chemical Company of Big Springs, Texas, reuses municipal effluent in low-pressure boiler feed make-up water. Treated municipal wastewater is being reused in New Mexico for mineral processing, cooling water, irrigation, and operations at Los Alamos Scientific Laboratory.

The water reclamation and sewage treatment plant of the city of Amarillo, Texas, has been satisfactorily providing reclaimed water to an oil refinery since 1955 and cooling water to a generating station since 1960 (71). The quality of raw effluent at the treatment plant dictates the cost of reused water. The reclaimed wastewater is also used as make-up water for the boilers of an electrical generating station. The wastewater reclamation system consists of a conventional activated sludge plant.

Industries within the industrial complex at Odessa, Texas, use city sewage effluent as the primary source of industrial water (72). Careful attention to the quality requirements of each water user also makes it possible to reuse significant quantities of wastewater within the plants in the complex. This reuse can sometimes be accomplished with very simple processing or even without any processing at all.

At Odessa, Texas, El Paso Products Company has in the past obtained 85 percent of its process water from the city wastewater treatment facility

(73). The treatment system at the industry includes lagoon, lime precipitation, recarbonation, and filtration, degasification, and ion exchange. After use of the reclaimed water for cooling purposes, it is then clarified, filtered, and finally sold to an oil-producing company for utilization in secondary oil recovery.

At San Diego, California, a reverse osmosis pilot plant was constructed for the purpose of providing reclaimed water for boiler feed and for cooling towers (74). The author described the renovation system, tabulated the operating conditions, and assessed the operating costs.

It has been established that certain electric generating plants can use significant amounts of treated municipal wastewater (75). For every gallon of treated water reused, one gallon is added to the total fresh water resources. The studies and experience of Southwestern Public Service Company at their Lubbock and Amarillo, Texas plants where sewage effluent is used as cooling and/or boiler make-up water indicates that sewage effluent is a valuable source of industrial water (76). The Nevada Power Company has successfully used sewage effluent for cooling blowdown purposes since 1957 at two of its generating plants (77). A power generating station in Lawton, Oklahoma, uses purified effluent from the municipal tertiary treatment facility as make-up for its cooling lake (78).

Various aspects of the use of sewage effluent as cooling water in power stations were discussed by Humphris (79). The Croydon Power Station in England has used sewage effluents for this purpose for 20 years. This use of sewage effluent has proven economical and beneficial to the waterway receiving the effluent (80). Wood (81) concluded that sewage effluent could be used in other applications to provide water savings.

The central Contra Costa Sanitary District 30-mgd wastewater recycling plant at Pacheco, California, will provide 17 mgd of treated wastewater to five San Francisco Bay-area industries: Phillips Petroleum, Shell Oil, Stauffer Chemical, Monsanto, and Pacific Gas and Electric (82). Physical-chemical treatment is necessary because water reused by the area industries must be low in phosphorus, BOD, and suspended solids. Treatment at the facility includes: flocculation, sedimentation, oxidation and nitrification, chlorination, denitrification, and dual-media filtration. Flett (83) described the Contra Costa County water reclamation project and industrial participation in the decision-making process to reuse municipal effluent for cooling purposes by several industrial plants. HorstKotte (84) discussed pilot plant operations.

Boler and Grounds (85) described a proposed combination sewage treatment-thermal cooling system in which mixed liquor from a channel aeration sewage treatment plant is pumped through the condenser of a power plant to remove rejected heat and then returned to the aeration channel where cooling and aeration are accomplished. The potential advantages of this type of combined treatment system are discussed in detail. The authors feel that the proposed combination system should result in about a 50 percent capital cost savings in comparison with separate sewage treatment plants and closed-loop cooling systems.

Mayes and Gibson (86) reported on the utilization of sewage effluent water for almost all refinery uses at the petroleum processing complex of Cosden Oil and Chemical Company at Big Spring, Texas, with problems listed that were encountered during 13 years of reuse. The most important consideration in choosing a water for use in a plant is the cost and quality. The industrial decision to use municipal sewage effluent water in lieu of some other source must, in the final analysis, be based on cost comparison where the quality is comparable. To aid a manager in choosing between sewage effluent and other sources, economic data were presented for the Big Spring refinery.

At the refinery of the Standard Oil Company in Lima, Ohio, the use of municipal wastewater treatment plant effluent was required when the city's treated water supply became inadequate (87). The authors described the reclamation system and discussed the operating results and operating problems that were encountered. Refining operations at Enid, Oklahoma, and at Santa Rita and Hurley, New Mexico, use treated municipal wastewater for all their water needs (50). The Enid, Oklahoma, plant of Champlin Petroleum Company uses municipal sewage effluent for all its water requirements (88).

Banerji (89) and Shah (90) described a system for processing municipal sewage and reusing it for industrial operations at the Union Carbide chemicals and plastics plant at Bombay, India. The cost of the reclaimed water is 60-65 percent that of municipal water.

After the investigation of potential solutions to water supply problems at a Dow Chemical Company plant, the alternative finally selected was use of the treated effluent from the wastewater treatment plant of Midland, Michigan (91). Water was provided that required only additional chlorination to be suitable for use as cooling water, service water, and for fire-protection systems.

A chemical-industrial complex in an arid region depends upon municipal sewage for its water supply (92). The sewage is subjected to screening, primary clarification, activated sludge treatment, lagooning, cold lime treatment, filtration, and ion exchange prior to use by industry.

Hofstein and Kim (17) described the successful use of treated municipal wastewaters in an integrated steel mill. Jacobs and Smith (93) described the refinement of tertiary treated wastewater by the flotation process to produce water suitable for use in the manufacture of bleached kraft pulp and fine paper.

Conradi and Smith (94) described the use of municipal wastewater effluent in large amounts for process purposes at a bleached kraft mill. The wastewater was successfully treated by addition of lime to pH 10.8-11.0, clarification, carbonation with CO_2 to pH 9.5 after settling, further carbonation, and sand filtration.

The use of the Baltimore, Maryland, sewage effluent by the Bethlehem Steel Company is perhaps the classic example of sewage effluent use for industrial purposes (88). This plant accounted for better than 50 percent of the sewage effluent utilized by industry for many years. A large number of mining operations in the southwest utilize treated sewage effluent as feed to their plants.

The intensive reuse of municipal wastewater for industry has made possible a high degree of industrialization in Monterrey, Mexico (95). Industry, using the final effluent from the domestic wastewater treatment plant, has solved the problem of lack of water, poor water facilities, and contamination (96). The industrial complex is dedicated to the manufacture of rayon, synthetic thread, and chemical products such as sulfuric acid, hydrochloric acid, chlorine, caustic soda, carbon disulfide, and refrigerant gases. Gomez (96) reported that about 60 percent of Monterrey's water was reused by over 30 industries.

The only way to utilize sewage plant effluent fully and successfully for industrial or other service is to evaluate each plant's characteristics and to solve problems involved in each application prior to development of a project (97). It is important to note that an industry will utilize sewage effluent if the industry has requirements for such water and if the sewage plant has sufficient effluent available at an economic price (88).

Although municipal waste is adaptable for limited reuse (cooling water and process water) with minor pretreatment, municipal treatment processes increase the total dissolved solids (TDS) level significantly which, in turn, increases water consumption, pretreatment costs, and internal treatment costs (42). Such increases in TDS levels do not occur in industrial process wastewater. Also, if municipal wastewater is to be used in steam generation systems, phosphorus removal is necessary; ammonia removal may also be necessary, depending on the use of the steam.

According to Fynak (98), the total cost of processing to meet quality requirements and delivering a reusable municipal wastewater will be the most important consideration for use by industry. However, recycling of wastewater within a plant is simpler and is being adopted more extensively.

Sewage plant effluent can be a valuable source of industrial water, but its degree of response to conventional chemical treatments must be carefully investigated for each situation (99). Three kinds of industrial water reuse systems were discussed: 1) a plant which recycles water within its own confines by a cascade system, 2) a plant down river which collects discharges from other plants and from the city, and 3) a plant which directly uses municipal sewage plant effluent.

Culver and Thomas (100) reviewed the methods used to reclaim usable water from municipal wastewater. Results obtained, costs of construction and operation, precautions to be observed in the use of reclaimed water, and alternative potential uses of reclaimed water were considered.

A paper mill using purified sewage as its major source of water experienced difficulty in meeting brightness demands for fine bleached paper due to the presence of residual organic matter and heavy metals in the purified sewage (101). Results of laboratory-scale investigations led to the recommendation of alum treatment prior to use.

SECTION 3

IN-PLANT WASTEWATER REUSE AND RECYCLE

A limited water supply plus stringent environmental requirements combine to provide industry with a strong incentive for maximizing reuse process wastewaters (34). While many ideas for industrial wastewater reuse have been published, each case is rather unique. Reuse of wastewater in applications such as cooling tower makeup, boiler feed water, fire water and plant service water, and crude oil desalting was discussed along with associated problems and their solutions. Two real cases were discussed in detail.

Companies throughout the United States are recycling more water and taking in less fresh water (102). This pattern is expected to hold for the remainder of this century. Intake reductions, as well as cuts in discharges, are being made possible by increased water reuse within the plant. Additional water reuse comes from taking in the effluents of other plants, e.g. municipal treatment units.

Rambow (103) expressed the opinion that treatment of industrial wastewaters for reuse makes sense for four reasons: 1) it conserves water, 2) it prevents pollution, 3) it will many times save money, and 4) it reduces corrosion. Recycling and reuse of wastewaters offers a way out of the zero discharge dilemma facing so many industries (104). In many cases, however, zero discharge is simply not achievable. The law of diminishing returns will render impractical most of the traditional effluent treatment processes. That last "fraction of a fraction" of a percent of a contaminant is by far the most expensive to remove.

The reuse and ultimate disposal of industrial wastewaters were discussed by Dean (105). Industrial wastewaters can be discharged after suitable purification; they can be evaporated; or they can be purified and reused.

Parish (106) discussed various aspects of the reuse of wastewater for industrial purposes. Multiple usage of water is suggested to reduce total water intake, save water costs, provide a water source where supplies of raw water are limited, and reduce the total amount of effluent to be discharged. The degree of ability to reuse water within a given industry depends on the nature of the industry, process wastewater characteristics, and process water quality requirements. Aspects of waste treatment systems to be considered include adaptability, versatility, resilience, cost, energy, ease of operation, and current plant size.

Bell and Goldstein (18) presented a systematic approach for establishment of an effective water reuse program. The approach is pertinent to all industries. Obviously, no single answer can be developed for any industry type, or even within industry types. Major factors which such a program must consider include: make-up water quality, individual use patterns, type of manufacturing (batch or continuous process), and degree of direct water contact with product or process streams. Focusing the effort on such total water use systems helps to integrate the separation between effluent problems and water user problems and clarifies the real opportunities for the total reuse of water in industrial process plants.

The most essential prerequisites for a successful reuse program are: 1) an internal need for a sufficient volume of water to balance its production, and 2) a process that can accommodate it (104). The case history of a successful recycle venture in the reuse of chemical process water was presented.

Water reuse or recycle both reduces the requirements of raw water and the volume of wastewater which has to be treated as well as the size of treatment plant required (107). In order for an industry to utilize water reuse, a detailed survey must be conducted to indicate: whether effluents are suitable for reuse or recycle with or without treatment; whether water is being used unnecessarily; frequency of use; nature and amount of contamination; and nature of treatments required. The status and prospects of water reuse in various industries were reviewed. Case histories from the food, electronic, and steel industries were included. Treatment techniques prior to water recycling were surveyed. Problems related specifically to each were described. It was concluded that in almost every industry recycle or reuse of water must be accommodated in the future for both economics and conservation. The first consideration of industry will remain direct savings accruing from minimized freshwater intake and process losses.

Companies in California are providing good examples of how to increase reuse. California has passed a law allowing allocations of virgin water only if manufacturing facilities prove an inability to operate on reused water, or inability to find reused water (102).

McClure (108) presented ideas about how industry may be able to treat a wastewater stream and then, instead of discharging it, recycle it through all or part of the manufacturing process. Types of industrial reuse and treatment for reuse were discussed. It was emphasized that there are no set programs.

Eden et al. (109) pointed out that when industrial water is reclaimed from wastewater effluent, complete treatment is not always necessary. Examples were given of different degrees of treatment and the industrial uses to which the reclaimed wastewaters could be put.

Eller et al. (49) surveyed the status of industrial water reuse and recycling by a presentation of representative case studies. The authors stated that in the majority of cases involving industrial reuse, it is necessary to provide some form of treatment and that several industries are using several forms of tertiary treatment in support of water reuse and recycle practices.

Ling and Kiester (110) reviewed internal reclamation and reuse of industrial wastes, including a discussion of pilot plant studies, choice of suitable treatment, and continuous monitoring. Mace (111) described a hypothetical case study evaluating recycle versus disposal.

In considering the employment of a reuse system, it is important to weigh the national impact of the system on lowering energy consumption and improving the quality of the plant waste discharge to eliminate or reduce industrial water pollution (112). These factors alone could be a deciding factor in the employment of the system.

Well-designed, complete, well-operated cyclic process systems are almost universally applicable and virtually pollutionless (113). They involve least depletion of resources, least discharges, and so least possibilities of environmental pollution. The benefits to companies, to the community, and to the environment of taking advantage of the requirement to reduce discharges to about zero levels are very large as compared to what will happen if remedial steps against present common practices are not taken.

According to Fritsche and Schima (42), the only type of industrial wastewater that can be considered for reuse is process wastewater. Cooling water and boiler water blowdowns are normally concentrated with respect to scale formation and corrosion, making these streams impractible for reuse under circumstances where further concentration occurs or adverse conditions exist. Although industrial wastewater may contain process contaminants which must be removed prior to reuse, its reuse may significantly reduce water consumption requirements.

Industrial cooling is both one of the largest uses of water and one of the largest examples of water reuse (114). Water can be reused repeatedly in recirculating cooling systems. Only the most essential, very minimum; and least expensive treatment is given the water. This may include straining, sedimentation, chlorination, and corrosion control.

Rey et al. (115) discussed and illustrated multiple use, reuse and/or recycle techniques in terms of three major functions of use: process use, cooling, and steam production. A hypothetical plan to purge limiting waste materials from the reuse/recycle system was also described.

Mace (116) provided a discussion of the reclamation of industrial wastewater for production processes and cooling. A flow diagram was presented to describe how much water should undergo treatment for reuse and where it should be reused. Primary, secondary, and tertiary levels of wastewater treatment were described. Factors which influence the feasibility of wastewater reuse are related to the relative effects of suspended solids, water temperature, dissolved solids, oily wastes, and process modifications to reduce overall water consumption. A cost analysis was presented for recycling 90 percent, 50 percent, and 0 percent of the wastewater produced at a typical plant. Typical space requirements for recycling were described.

Rickles (88) discussed water reuse in the chemical processing industries. He observed that the American practice of water reuse is widespread and varied. Specific industries reviewed were chemical manufacturing; petroleum refining; pulp and paper; iron and steel; mining, metallurgical, and nonferrous metals; and food processing.

Reuse of water and reclamation of effluents arising from unit processes in a factory can result in a savings on water consumption of between 50 and 90 percent (117). Water requirements of several South African industries before and after reclamation and reuse were compared.

Bischofsberger (118) described the applications of closed water circuits by wastewater treatment and recycling in industrial processes in West Germany. Water circuits may be in the cascade or open system with wastewater from one stage of the process being suitable for use in a subsequent stage, or in a closed system, with the process wastewater being returned to the same process after adequate treatment. Examples were presented.

LeClerc (119) discussed water reuse in the iron, coal, mining, sugar, and paper industries in Belgium. He observed that recirculation seems to be a solution to many different industrial problems, either to save as much purified water as possible, or to limit the wastewater discharged into sewers or rivers.

Wolters (120) reported that the great concentration of water-using industries in the Ruhr Valley, and the need to minimize pollution of the River Rhine, forced maximum inplant reuse of water. Special efforts are made in new plant design to make more effective reuse possible. One steel mill completely reuses all incoming water. Special problems with beet sugar, coal mining, electroplating and heavy chemicals industries are discussed.

Meucci (121) described three Italian reuse plants: in a sugar factory, washing and conveying waters are recirculated after simple sedimentation and sterilization; in a metal-working factory, acidic and alkaline waters are reused after being singly treated for removing cyanide and chromium and then mixed, neutralized and clarified; in a steel mill, acid-washing waters and cooling waters are recirculated after oil removal, addition of hydrated lime, clarification by ferrous sulfate, and cooling.

Lazarescu (122) outlined actions taken in Romania to prevent water pollution and to develop water resources of good quality. The quality of water needed for various uses is defined. Water reuse in industrial units and processes to recover valuable products formerly discharged into polluted waters are discussed.

Varma (123) examined water use and reuse requirements in India. Water reuse in textile mills and chemical and pharmacentical industries were reported as having high potential.

FOOD PROCESSING

Water is absolutely necessary for many steps in the food processing industry; there is no economical substitute at present. The food industry, as a whole, uses prodigious quantities of water (124). Consequently, water conservation and water reuse are necessary, and most of the industry practice reuse in order to conserve this vital natural resource and reduce operating costs. In addition, the amount of liquid waste is reduced as is the pollution potential from food processing operations. Major efforts are being made by the food industry toward water pollution control, both within the processing plant and through advancements in wastewater treatment technology. The highest priority consideration is overall plant sanitation and quality of the product. Water conservation and reuse are practiced as much as possible, but there is a limitation to the amount of recirculation and reduction of high water requirements that can be accomplished and still maintain satisfactory sanitation conditions. Quality is the most essential factor, and therefore, sanitary conditions of operation are the controlling criteria for the reuse of water.

Wilson and Huang (125) discussed water use patterns of the food processing industry. The major cost-effective water conservation measures undertaken to date, can be classified under the areas of: 1) use consciousness; 2) cooling water conservation; and 3) counter-current reuse of process flume water. Efforts of food processing firms to comply with BPT requirements have brought about overwhelming reductions in wastewater throughout the industry. There are a number of published case studies describing how certain firms have achieved the ultimate objective of zero wastewater discharge. Such changes in use patterns are expected to continue.

Although quantities of food processing wastes generated annually are massive, and production takes place mainly during the summer months when assimilative capacities of receiving waters are minimal, significant progress in the areas of waste reduction, wastewater recycling, by-product development, and waste treatment have been made (126).

Anderson (127) discussed developments in effluent treatment related to the food industry in England. Water recycle systems must be considered due to the increasing costs of raw water and waste discharges. The process of counterflow rinsing should be considered in an attempt to save water.

Alikonis and Ziemba (128) discussed the proper handling of food wastes, cost of treatment, in-plant control, preparation, water conservation, waste segregation, and water reuse. Alternate treatment methods were described briefly, as were common problems associated with treatment.

Hoover (129) examined various major processing changes for reduction of wastes and concluded that meeting the goal of zero discharge would require process modifications to produce concentrated waste fractions which can be dehydrated, extremely effective biological treatment, or dry processing methods.

Dloughy and Dahlstrom (130) reviewed the design of food and fermentation waste disposal facilities. They concluded that waste and water reuse processes as well as any byproducts recovery systems should be considered an integral part of the entire plant scheme to minimize future capital and operating expenditures.

Water problems and reuse of water in the food industry were discussed by Treanor (131). An example of water recovery for process reuse in vegetable processing was presented. Bowen (132) presented a short review of waste treatment practices and their application to cannery wastes. The relatively high cost of treatment was emphasized, and good housekeeping coupled with maximum water reuse was recommended.

Joyce (133) reported the use of a hydro-cyclone solid-liquid separator and pressure filter at a Canadian cannery for solids removal. Recirculation of the chlorinated water was estimated to save 45 percent of the total water requirement.

The National Canners Association evaluated the performance and effectiveness of a super-rate trickling filter, acidified flume water system, air flotation, and circular vibration screens in reducing food processing waste strength (134). Sanitation was improved with acidified recirculation water, and 75 percent of the fresh water was saved.

Esvelt (135) reported on the investigation of reclamation of biologically treated effluent in a cannery by filtration through mixed media pressure filters and disinfection with chlorine. Reclaimed water was put to several trial uses: 1) initial product conveying; 2) equipment, floor and gutter washing; 3) direct container cooling; and 4) boiler feed. Steam generated from reclaimed water was used on a trial basis for equipment cleaning, exhausting, cooking, and blanching. Reuse of reclaimed water was found acceptable except during periods of high suspended solids. No degradation of the product was produced as a result of reclaimed water use during these trial runs.

Since 1977, the Oconomowoc Canning Company, Paynette, Wisconsin, has filtered and reused water from vegetable cooking operations as boiler feedwater and in some cooking operations (136). The continuous recycle of this hot water between cooking operations and the boilers has resulted in considerable operating cost savings because of decreased fuel requirements for water heating.

A report on water quality factors to be considered during the recycle of water used in canning green beans revealed appreciable water savings (137). Streebin et al. (14) reported on a study directed toward development of a water conservation and reuse program at the Stilwell Canning Company in Stilwell, Oklahoma. A summary of the results are presented. It was noted that due to the many similarities in processing operations in canneries, development of a water conservation and reuse program for one cannery would be of general applicability for many canneries.

Preparation of seasonal fruits and vegetables for preservation generates enormous volumes of liquid wastes and solids residuals (138). Increased costs of waste management have forced the food industry to modify traditional processing practices. Conservation measures and operational changes, such as counterflow recycle use of processing water, have resulted in major reductions in liquid waste generation rates.

Plowright (139) discussed alternatives for wastewater treatment, disposal, and reuse in the vegetable processing industry. The most economical treatment was determined to involve primary solids removal followed by a biological stage. MacGregor and Parchomchuck (140) used a gas-fired steam generator to concentrate recycled effluent from vegetable blanchers.

Barrett (141) discussed vegetable-processing waste minimization and treatment practices in Great Britain. The reuse of effluents after activated carbon or reverse osmosis treatment and chlorination or ozonation were advocated for certain applications. Wright (142) described tests of an improved leafy greens washing system using water recirculation to characterize the quality of the washwater and wastes and to make comparisons with conventional washers. The test system produced a cleaner product while reducing waste requirements and consolidating waste loads. Hoehn et al. (143) reported on a project initiated to design, build, and test a full-scale, immersion-type washer that would recycle the washwater during greens-washing operations. These workers concluded that recirculation of washwater in immersion-type, leafy-green washing systems is a promising modification of existing processing methods for reducing water consumption and concentrating waste loads so that they can be more easily treated.

Wilson and Huang (144) examined washwater recycle flow schemes from a tomato processing plant. Comparisons were made between conventional cleaning (with and without recycle), disc cleaning with recycle, and disc cleaning with recycle plus chemical coagulation/flocculation. When compared with the conventional scheme without recycle, a 26 percent increase in tonnage of tomatoes processed was obtained with disc cleaning with recycle plus chemical coagulation. Water consumption also decreased by 41 percent.

An in-plant water recycle system with off-line mud removal was demonstrated for the tomato processing industry (145). The system could result in approximately 50 percent savings in the total annual wastes/water-related costs in the industry. The system, installed at a 35 ton per hour plant, included a solids trapping false bottom, an ejector for solids transport, a screen with screening discharge hopper, a soil solids separating swirl concentrator, a sludge thickener, and a chemical coagulation/flocculation system. The system was operated in four modes: conventional cleaning, conventional cleaning with water recycle, disc cleaner, and disc cleaner with water recycle and chemical coagulation/flocculation. Use of the disc cleaner and water recycle system increased the daily average tonnage of tomatoes processed because solids did not accumulate in the dump tank and impair product flow. Total daily water usage decreased by 26 percent with use of the disc cleaner with water recycle and chemical coagulation/flocculation.

A waste-eliminating beet peeling system coupled with controlled chemical treatment installed at a Wisconsin Cannery reduced the BOD by 85-90 percent (3500-4000 ppm to 50-75 ppm) after lagooning and caused a 50 percent drop in the hydraulic load (146). Measures were being initiated to minimize production of waste and to conserve water by recycling.

Alternatives in formulating a wastewater management program are exemplified in the development of a phased program by a carrot processor (1). The three-phase program included: evaluation of soil solids removals and water reuse systems; pilot evaluation of the system for suspended and colloidal solids rinse; and design, installation, and startup of full-scale solids removal and water reuse. Reductions of all parameters were noted at each step of the process, and water was suitable for reuse and discharge. The operation demonstrates the effectiveness and economy of a phased approach for developing a waste management program. Treatment consisted of screening, settling, coagulation, settling, and filtration. A large California carrot processor successfully recycles nearly all wash and flume water (147).

Holdsworth (148) summarized the nature and composition of effluents from fruit and vegetable processing industries in the United Kingdom. A survey showed that water usage was in excess of 750 million gallons annually for vegetable canners alone, corresponding to a production of over 700 thousand tons of vegetables. General operations were similiar for every process, although each product has its own special equipment. Methods which utilize water reuse and recirculation have increased, especially the use of countercurrent methods for washing and cooling. A typical water recirculation system used for pea freezing was illustrated.

Eckenfelder (149) presented a comparison of the cost of in-plant versus end-of-pipe treatment of various fruit and vegetable processing wastewaters. In plant modifications were economically justified in nearly all cases.

The unusual problems associated with wastewater minimization and treatment at an artichoke processing plant were discussed by Perkins (150). In-plant wastewaters conservation reduced water usage from 400,000 gpd in 1958 to 40,000 gpd (151 cu.m/day) in 1968.

Thompson and Esvelt (151) examined the potential for reclamation and reuse of fruit processing wastewater and found it technically feasible to reduce wastewater discharge and water demand by over 50 percent. The consistency of renovated water quality along with physical, chemical, and bacteriological quality were considered critical in determing where water could be reused.

Activated sludge treatment of citrus wastes followed by lime treatment and in-plant reuse were discussed by Jones (152). He concluded that the treated effluent could be recycled, the waste sludge could be used as cattle feed, and high excess solids production could result from the process.

A full-scale, complete-mixed activated sludge treatment system treats wastewater from the Winter Garden Citrus Products Cooperative (153). The treatment plant effluent is reused for barometric leg and cooling water before being discharged. Reuse of the treated water has resulted in an approximately 25 percent savings in annual operating costs of the treatment system.

Stone (154) reported on the commercial application of dry caustic peeling of peaches. He demonstrated that a reduction in freshwater requirement of nearly 90 percent was feasible. Lower operating costs and reduction of damage to fruit during peeling were also claimed.

Leavitt and Ziemba (155) discussed the multiple water reuse system of the Gerber Products Company plant at Fremont, Michigan. Various water-savings devices were mentioned and the concurrent saving of heat was emphasized.

A review of the literature pertinent to the production and treatment of potato processing wastes was presented by Stephenson and Guo (156). The report outlined unit operations employed in the industry with emphasis placed on the french fry and potato chip section. Data on the quantity and quality of wastes generated from each unit operation were collected and analyzed. In-plant measures for water conservation, water recycle and by-products recovery were demonstrated as potential methods for reduction of waste loads.

Water use and wastewater reuse studies were conducted at three potato processing plants whose major product was frozen french fried items (157). Wastewater characteristics of specific process lines were presented for each plant. A scheme for more complete reuse of the wastewater in processing was proposed based on the in-plant investigations.

Lash et al. (158) reported that there is a practical economic way to remove organic pollutants and suspended solids from potato processing wastes, and it produces effluents that for the most part can be recycled. The economics and processes which make possible the recycle of treated potato processing liquid wastes were shown. Basically, the process involved screening course solids, primary clarification of fine solids, and filtration of underflow solids to produce cattle feed. The primary effluent was treated by the activated sludge process. Tertiary treatment by granular medifiltration removed the final solids. After chlorination, a major amount of the treated water was recycled to the processing plant for many uses. Expensive local water costs and high sewer costs add incentives to use of recycle.

Hautala and Weaver (159) reported on methods of reducing pollution from the cutting phase of potato processing. After a two-stage filtration step, the cutting water could be recycled and the solids recovered from the washwater.

Gransfield and Gallop (160) discussed the conservation, reclamation, and reuse of solids and water in potato processing. Plowright (140) described biological treatment systems for potato wastes and techniques for using recovered water for prewashing and peeling after filtration and chlorination.

A study of water conservation and reuse in potato processing plants indicated 18.8 percent of the total intake per day could be reused with little or no further treatment. An additional 14.6 percent could be reused if suspended solids were removed and treatment to reduce microbiological populations was applied (161). This applies to a specific plant. Because of wide variations in plant methods, individual plants should be surveyed before recommending water reuse.

Disinfection with chlorine dioxide permitted a Pacific Northwest potato processor to reuse some process water up to three times in successively less critical processes (162). Water usage was reduced 30 percent.

Hydamaka et al. (163) discussed a closed-loop recycle system for potato rinsing as well as methods for treatment and recovery of rinse water constituents. Activated carbon was evaluated as a means of controlling enzymatic browning. Colston and Smallwood (164) reported on waste control methods used in a sweet potato processing plant, including dry caustic peeling and pretreatment methods.

Allen (165) described the water reclamation system at an instant mashed potato plant in Yorkshire, England. The design, construction, operation and economics of the system were reviewed. Shaw and Shuey (166) described a new method of potato starch production that would reduce wastes by 90 percent.

The use of anion exchange resins for removal of acids from potato starch factory wastewater after prior removal of proteins and amino acids was studied by Schwartz et al. (167). The process removed over 99 percent of the acids. Data were given on the effect of effluent temperature and flow rate on column efficiency during the acid adsorption step. Increasing the alkalinity of the eluating agent or recycling the eluate were listed as methods of increasing the concentration of acids in the eluate. Possible uses of the eluate were also discussed.

Secondary wastes from potato-starch processing can be treated by reverse osmosis (168). This material contains protein, free amino acids, organic acids, sugars, inorganic acids, and other compounds. In a pilot test, the recovered water was pure enough for reuse. The best choice of the three types of membranes tested was the one of medium porosity. This conclusion was based upon the relationship between flux, retention of desirable wastewater constituents, and reduction of COD.

Besik (169) discussed the potential and reported uses of the reverse osmosis process as they apply to the starch industry, to other industries and to water reclamation. Problems encountered were addressed. Besik (170) feels that reverse osmosis is suited particularly for treating wastes from starch manufacturing plants, because both the permeate and concentrate can be reused and recycled.

The practice of recycling wastewater has become increasingly successful in the beet sugar industry (171). It has been demonstrated that a factory which recycles water does not need to discharge any wastewater during the processing season. A comprehensive discussion of the practice is presented. The practice of recirculation reduces the overall water volume, reduces the amount of water subjected to pollution thus reducing the size and cost of facilities needed to maneuver and treat the water. Most beet sugar factories recycle at least some of their process water.

The beet sugar industry uses water for transportation, as well as processing, and produces very highly contaminated wastewaters. Miles (172) described optimum uses and reuse at the Hereford, Texas plant of the Holly Sugar Corporation. A clarification, recirculation, and impounding system was installed. Description sketches were given to illustrate the reuse processes and facilities.

An average of 2,200 gallons of water is required per ton of sugar beets for fluming and washing operations. Brenton and Fischer (173) reported on a two-year study conducted within the industry on the containment, treatment, recirculation, and reuse of sugar beet fluming and washwater. The particular system studied included two alternately used first ponds in series with a second pond. At the end of the processing season, the system and surface waters were discharged into an aerated pond for treatment. Water was not discharged from the final pond but used as fluming and washwater during the next processing season.

Crane (174) described advances toward reuse of water in the beet sugar industry. Process technology was explained as a means of understanding the effective reuse of wastewater. Flow diagrams showing systems without reuse and with complete reuse were presented.

Smith (175) gave a description of inplant reuse that reduced water requirements by greater than 97 percent in the processing of beet sugar. By using various treatment processes and recycling, the amount of wastewater produced was reduced from 1,200 to 30 tons/100 tons of beets processed in a beet sugar processing operation.

Bickle (176) discussed procedures used in the treatment of sugar-mill wastewater effluents before discharge into a creek in Queensland, Australia. Recycle was used in combination with aeration.

Fischer (177) undertook a study to develop a closed-loop wastewater treatment system for flume water used for conveying and washing in a sugar beet factory. Recirculation of flume waters was shown to be possible. An aerobic pond effectively treated the total flume water after each operating cycle. Although the treated produce water also met discharge standards, it was reused in the system.

The California and Hawaiian Sugar Company installed a 1.8 mgd biological treatment system to renovate water from its Crockett Refinery and from the adjacent Crockett-Valona Sanitary District (178). Water not reused in the refinery is diluted with San Francisco Bay waters before discharge.

Paxson (179) reported on the construction of a sugar beet factory in North Dakota which would have a slicing capacity of 5,000 tons of sugar beets per day and a yearly production of 75,000 pounds of sugar. Braunschweigische Maschinenbauanstalt (BMA) of Germany was responsible for its design and construction. All the water at the facility would be recycled.

A sucessful project by Manitoba Sugar Company, Fort Garry, Manitoba, to reduce river pollution by eliminating sugar beet processing wastes was described by Blankenbach and Willison (180). A recirculation system was put into operation in 1965. The system consists of screening, clarification, coagulation, and sedimentation. Clarifier overflow is recirculated to the flume water supply tank. It is felt that the increased concentration of dissolved solids in the recirculation system produces significant savings of sugar by reducing osmotic pressure differentials.

Zero discharge was successfully achieved using a contact stabilization package plant for treating soy sauce wastewaters in Wisconsin (181). A two-step membrane process has been demonstrated for the treatment of soy whey (182). In both laboratory and field pilot studies, ultrafiltration and reverse osmosis were used to produce protein and sugar concentrates as by-products, and a low BOD effluent. The soy whey is first introduced into a low pressure UF unit. The permeate from the UF unit is introduced into a RO operation. The final effluent from the RO section can either be reused within the plant or discharged.

A series of 24-hour tests were made in a commercial soybean oil refinery under eight different operating conditions to select optimum conditions for a subsequent longer test of the antipollution recycle-washing process in which wash water would be recycled instead of being discarded (183). Operating and analytical data, equipment specifications and cost data were acquired. The new recycle process will provide an economic solution to the wash water disposal problem.

Research by Lewis (184) showed the feasibility of recycling process waters in the beer brewing industry. Data were presented indicating recycling did not affect the quality and flavor of the beer. McKee and Pincince (185) reviewed water quality requirements and washwater characteristics of a typical brewery. Techniques for water conservation and advanced treatment methods for partial or complete recycle were included.

Preparation of olives for canning creates a strong liquid waste which is high in both BOD and sodium chloride content (186, 187). In this study, storage brines and processing waters from the production of canned and glass-packed olives were treated with activated carbon. The reuse potential of reconditional brines were evaluated. Canned samples prepared from olives stored in reconditioned brines were of good quality. Reconditioned concentrated brines can be used to store freshly harvested olives for at least six months. Reconditioned brines of lower salt content were reused with no detectable effect on quality of the final product. Cost estimates for the activated carbon treatment system were given. Treated lye rinse waters were reused in commercial production with no detectable effect on the quality of the canned olives as judged by production personnel. There is considerable promise of using carbon treatment of processing waters to condition these liquid wastes for reuse at considerable savings in potable water and reduction of salt pollution potential. It was concluded from this study that the reconditioning and reuse of olive storage brines is a commercially feasible process.

Brines used for bleaching, curing, and preserving sweet cherries were made reusable by treatment with activated carbon. Reuse required the removal of dissolved pigment in the used brine (188). Cherries packed in the reclaimed brine were of higher quality than those used in the control. It appeared that the brine could be reclaimed and reused several times. Savings would result not only from lower requirements of chemicals for making brine, but also from reduced sewage charges when discharging into a municipal sewage system.

Problems associated with the disposal of strong calcium bisulfite brines used in the cherry processing industry led to an evaluation of recycling as a means of alleviating pollution caused by residual sulfur dioxide (SO_2) in the brines (189). Preliminary experiments using activated carbon treatment, sand filtration, and addition of SO_2 and lime have produced a product similar in composition, color, and firmness to that of fresh brines.

Little et al. (190) conducted industrial water and wastes surveys at two pickle companies. Water usage and waste characteristics were determined on major unit operations. Laboratory and pilot-scale studies were performed to evaluate potential for recycling concentrated tankyard brines. Both a high pH coagulation-precipitation procedure and an ultrafiltration procedure were investigated. A "desk-top" evaluation of various brine treatment processes compared their cost effectiveness. The study indicated that in-plant water and salt usage could be substantially reduced by closer management and better housekeeping; that tankyard brines could be treated and reused at least once with no sacrifice of product quality; and that existing wastewater treatment facilities (aerated lagoons) could be upgraded to improve BOD and solids removal. Results of the study provided a detailed characterization of the types and concentration of components of waste streams from unit operations in cucumber pickle production.

Laboratory and in-plant studies have led to the development of a method for treating spent cucumber brine for recycling (191). The recommended system includes adjusting the pH of the brine to 11.0 with sodium hydroxide followed by a 48 hour settling period, and adjusting the pH of the clear brine to 7.0 with hydrochloric acid. The precipitate can be incinerated to recover the salt and reduce waste disposal problems. This method results in an actual savings in the cost of treating brine due to the recovered salt. This does not include any savings on sewage costs and surcharges.

Brine wastes in the cucumber pickle industry were studied by Horney (192). Regeneration of these wastes for subsequent reuse was considered the most feasible method of treating these wastes. Two methods of regeneration were studied in detail: 1) chemical coagulation-precipitation with lime and sodium hydroxide to pH 11.5 followed by neutralization with acetic acid, and 2) ultrafiltration.

Two brine treatment procedures, heat treatment and chemical treatment, were commercially evaluated for their feasibility in recycling spent cucumber fermentation brine (193). Results showed that brine recycling was practical on a commercial scale. Either treatment procedure resulted in salt stocks which were equivalent in quality to control cucumbers.

The lye (or alkaline) solution employed in the initial working of fresh olives becomes contaminated with organic impurities. Because the BOD of this waste is extremely high, it cannot be released into municipal sewage systems without first being diluted with large quantities of water. An invention by Teranishi and Stern (194) provides a means for obviating the problem. Contaminants in the lye solution are removed so that the purified liquor can be recycled. Only the settled contaminants must be disposed of; and since the volume of waste is small, disposal is not difficult. In fact, it may be used as fertilizer because it contains only organic contaminants, the lye having been removed and recycled.

Smith (24) discussed the reuse of wastewater in the poultry processing industry. Some basic theories on wastewater reuse were presented:

1. First flow through those processes requiring highest-quality relating to priority of microbiological content or suspended or dissolved solids. The next step is to try to find other processes that can use this effluent with or without further treatment. Note that U.S. Department of Agriculture closely regulates the types of water reuse, and the methods of water use in edible food operations.

2. If a cooling process is involved, try to use the effluent where warm water is needed.

3. If a heating process is involved such as a thawing operation, try to use the effluent where cool water is needed.

Stricter regulations on water pollution combined with the economic factors regarding water--purchase, disposal, and cooling--dictate that water reclamation be a primary goal of the poultry processor (195). Large quantities of water are used in poultry processing plants. On the average, 10-12 gallons of water are used to process a two to three pound broiler. Recycling holds the greatest potential for eliminating some of the large amounts of water used. A demonstration project to demonstrate the feasibility of recycling water in the chiller portion of the poultry processing plant was discussed. Some specific results of such a system should be:

1. Savings in water consumption.

2. A decrease in the amount of waste effluent from the chiller.

3. Savings in refrigeration.

4. Technology that can be used at additional locations in the poultry processing plant and other food industries.

Reuse of wastewater in the food processing industry is often constrained by the requirement to meet potable water standards (196). A system using microstraining, flocculation, sedimentation, and filtration achieved this goal in the poultry-processing industry.

Studies were conducted on recycling chiller water in a poultry processing plant (197). The recycling system must be provided with the capability of removing solids and controlling the microbial population. Ultraviolet light was used to control the microbial population. Pilot-scale results showed that filtration with diatomaceous earth was the most feasible treatment option studied for removal of solids. Filtration also maintained the bacterial level below that of the nonrecycled system. Operating costs for the filtrations system were approximately 45 percent lower than normal operating costs of the chiller without recycle.

Crosswhite et al. (198) presented benchmark information on water and waste quantities, wastewater characteristics, and biological characteristics of both the product and water at selected points throughout the Gold Kist, Inc. poultry processing plant at Durham, North Carolina. Areas of water use reduction were defined. Waste reduction measures resulted in an approximate 25 percent reduction in water use. Crosswhite (199) presented a case history of the project. Results were described of water use and waste load reduction measures and the economic analysis of such reductions. All of the process and equipment changes developed in the project increased net revenue and would be economically feasible.

Love (200) described the design and operation of a poultry processing waste treatment system including water reuse. The system included screening, aeration, clarification, lime and alum treatment, further clarification, filtration, chlorination, and sludge transfer to a lagoon.

Berry et al. (201) investigated the feasibility of reclaiming and recycling poultry processing wastewater by chemical coagulation, dissolved air flotation, sand filtration and activated carbon absorption. It was concluded that clarification, followed by dissolved air flotation, could be used for preparing chiller wastewater for filtration followed by activated carbon absorption to produce water suitable for implant recycle.

McGrail (202) examined health and safety aspects of the reuse of poultry processing wastewater. Lillard (203) studied water recycling in poultry-processing plants and disinfection. Andelman and Clise (204) studied the internal recycle of poultry-processing wastewater in a phased demonstration program. The treatment system for chlorinated double lagoon-treated effluent included microstaining, flocculation/sedimentation, sand filtration and rechlorination, followed by normal raw water treatment. Results suggested that renovated water quality compared favorably with that of the raw well water source.

Hamza et al. (205) reported that approximately 65 percent of the process water used in an Egyptian poultry processing plant could be saved through process modifications. A multiple water use system instituted in the plant included recycling the second chiller water to the first chiller; reusing washing water as makeup in the scalding operation; and continuously feeding uncontaminated compressor cooling waters to the scalding tanks. They also noted that modifications of the evisceration process and renovating and recycling of condenser water would also reduce water usage.

Performance and feasibility of various alternatives for pollutant reduction available to the poultry processing industry were discussed by Woodard (206). Typical poultry processing operations, wastewater sources, and flow and pollutant loading were described. Three alternatives for reducing the discharge of pollutants were presented. The first includes chemical coagulation and dissolved air flotation of combined flows followed by sand filtration and activated carbon. The second involves effluent flow reduction through process changes to replace water-using steps with dry processes. The third alternative involves physical-chemical treatment with screening, chemical coagulation, dissolved air flotation, sand filtration, activated carbon adsorption and disinfection to allow reuse of water for each individual process. Results of technical feasibility studies and cost analyses for the alternatives were presented.

A typical broiler processing plant was used to evaluate changes in equipment and processing techniques to reduce water use and waste load (207). Production at the plant was through two processing lines and totaled approximately 70,000 broilers per day. Results indicated that water use per bird received was reduced by 32 percent. Changes made were detailed. Economic analysis showed all to be profitable for the plant. A water and waste management plan was detailed. Microbiological analyses indicated no deterioration in product quality as a result of the changes.

Poultry processing plant chiller effluent is normally discharged to the sewer with no reuse of water (208). By recycling the chiller water, a processing plant could make substantial savings per year in water and refrigeration costs.

Norbest Turkey Growers Association utilized the "Dri-Flo System," a waste-handling system using stainless steel belts, to correct wastewater effluent in their Utah primary processing plants (209). The system saved 400 gpm of water. Overflow water from washing basins was recycled by filtering through diatomaceous earth and chlorination. Plant production was doubled without doubling water usage. The system employs a series of processing units for hydrolyzing solid wastes that are dried into animal meal. Economic evaluation of the system indicated an operating profit.

Witherow et al. (210) viewed the meat-packing process for the standpoint of its use and discharge of water. The concept of integrated water management through in-plant control, solids recovery and disposal, wastewater treatment, and water reuse was presented.

Fullen and Hill (211) pointed out that reduction of waste volumes by reuse of clean cooling and condensing waters, without passing them through the treatment plant, would result in a substantial decrease in the cost of treatment facilities in the meat packing industry.

Corban (212) explores new methods for the treatment of wastewaters and the reuse of water in the meat industry in New Zealand. Incentive for the investigation of the wastewater situation in the Shortland Works, Auckland, New Zealand, was increased by the cost of waste treatment and water. The problem was approached by instituting a water audit in each department. Results of the audit defined the use and possible reuse of water within the plant.

TEXTILES AND SYNTHETIC PRODUCTS

Boudreau (213) reviewed water quality problems central to the textile industry. These involve: producing water suitable for the processing of textile products; supplying water suitable for boiler feed in power plants; and, preventing corrosion in metal tanks and pipe lines. Many of the textile industry processes require water of a high grade and known quality. Some forms of water reuse will reduce the costs of process water. Appropriate methods for recycle are dependent upon costs of water and effluent disposal, limitations of water supplies, and local conditions.

A general approach for textile waste treatment was given by Leatherland (214). He discussed sources of pollutants in the textile industry and reviewed the potential of both conventional and advanced waste treatment processes for renovating textile waste discharges for reuse and recycle purposes.

Porter and Sargent (215) provided a comprehensive examination of wastewater treatment techniques for the textile industry. Recovery of reuseable chemicals, water and energy was considered. Wastewater problems of the textile finishing industry were presented by Stiebert (216). Several practical solutions to these problems were discussed. Water conservation through recycling is gaining in importance.

Water reuse in the textile industry was discussed by Laude (217). Seven methods of reducing water use in the textile industry including recycle and renovation and recycle were described, but it was indicated that zero discharge could not be achieved (218). As a result of water recycle, higher-strength wastes will have to be treated before final discharge.

Gardiner and Borne (219) examined the influence of the use of water and chemicals and the volume and characteristics of process effluents on water reuse in the textile industry.

Parish (220) indicated that water for reuse in the textile industry must have a low level of color and suspended solids, moderately or low levels of total solids, with less concern for BOD or COD. He evaluated wastewater treatment systems with respect to producing an effluent for reuse in the textile industry. Treatment methods which are examined include conventional biological treatment, flocculation, activated carbon, ion exchange, pretreatment, direct catalytic oxidation, reverse osmosis, and multi-stage evaporation.

Parish (221) reviewed treatment methods and cost factors for textile processing effluents. Water quality standards necessary for reuse of processing effluents are presented. Reuse of treated or untreated process baths can reduce costs. Further cost reductions can be realized by waste heat recovery.

Potential cost savings through in-plant modifications and controls for the textile industry are outlined by Atwood et al. (222). These include reduction of process water; reuse of cooling, printing, and effluent waters; recovery of several agents; handling of effluents; and cleaning of waters. By designing strategies for process-water and chemical consumption, reuse, and treatment to meet the specific needs of the mill facility, effluent requirements should be economically met.

Waste treatment methods and practices used in the textile industry have been studied (223). The literature was reviewed and an annotated bibliography prepared to supplement information obtained from people working in the industry, designing waste treatment plants, and enforcing state and federal water pollution regulations. It was concluded that more research was needed on water reuse in textile plants.

Mair et al. (224) cited recovery of chemicals and water from textile effluents as a cost-effective means of pollution abatement. General characteristics are presented for wastewater produced at a cotton finishing plant, a dyehouse, and a bank note printing press. Sodium hydroxide has been recovered from cotton textile mill discharges through evaporation and dialysis. Application of the Envirotech Salt Recovery Process, used for pulp and paper mill wastes, to textile mills wastes is suggested. Various processes have been considered for recovery of carboxymethyl cellulose (CMC) and polyvinyl alcohol (PVA). Chemical precipitation with metallic salts has been used to recover 75-85 percent of the CMC in sizing bath effluents for reuse, while adsorption and molecular filtration have been used for PVA. Research on use of activated carbon in the treatment of textile wastewaters for reuse is described.

Several processes available for treating textile effluents for reuse were described by Dettrich (225). The systems were discussed in terms of both costs and performance. Porter (226) concluded that it is both economically desirable and technically feasible to reuse treated wastewater in the dyeing and finishing industry.

Paulson (227) proposed wastewater treatment and reuse as an alternative to solvent dyeing. Complete regeneration and reuse of the effluent stream were proposed as the best solutions to textile waste treatment problems. Dixit (228) discussed the quality of water for reuse, methods of reducing water consumption, and steps required to achieve recycle.

Rouba (229) considered the use of water with a low degree of impurities in a closed-circuit system. He discussed various methods for treatment of textile wastewaters to this end. Sedzikowaki and Dobrowolski (230) described work on water reuse carried out at the textile Research Institute at Lodz, Poland. Arceivala (231) presented a detailed review of water reuse practices of the textile industry in India. The review covered direct in-plant use, reuse after treatment, and reuse of the effluent in irrigation.

A discussion on reuse of industrial wastewaters produced in the United Kingdom textile industry has been prepared (232). Methods of textile water renovation being investigated include hyperfiltration or reverse osmosis with different types of membranes. Costs of treatment were discussed. Techniques for conservation of process water used in the wool industry for scouring, rinsing, and dyeing processes were described.

Porter et al. (233) presented product changes that have occurred in the textile industry and discussed their suitability for biological treatment. When requirements for quality of wastewater discharged approach requirements for water for process use, it becomes feasible to consider water renovation and reuse within the mill.

Experimental studies have shown that wastewater from a textile dyeing and finishing operation can be recycled (234, 235). Wastewater was run through a set of hyperfiltration membranes which separated it into purified water and a concentrated dye residue fraction. Over a 15-month period, up to 90 percent of the wastewater was recovered and used as the normal supply in all parts of the dyeing operation. Concentrated dye residues can also be used to dye fabric. Detailed performance data were tabulated for the different types of membrane materials used. Cost estimates were given for the different membrane configurations.

A textile finishing plant processing most synthetic fibers achieved 87 percent water recovery using hyperfiltration through dynamically formed dual-layer hydrous oxide-polyacrylate membranes on porous ceramic and carbon tubes without deterioation of membrane performance (236). The purified product and the concentration residue from treatment of the dye waste have been directly reused in critical test dyeings. This may provide an important economic advantage. Since wastewater can be treated at process temperatures, the reuse of hot water will also reduce costs.

Effluents from production of cotton and cotton-synthetic and regenerated fiber fabrics purified by coagulation, and effluents from production of regenerated cellulose and synthetic fiber fabrics purified on sand filters, were subjected to additional purification by sorption on granulated activated carbon in a three-column reactor (237). Results indicate that this method of additional purification is not only effective in removing impurities but also presents the opportunity of achieving a closed cycle of process water. Flexibility of the process makes it possible to control the degree of purification desired. The method is economically justified only when applied to effluents that have been tested chemically or biologically or to effluents with a low concentration of impurities, such as wash waters.

Brandon et al. (238) conducted field evaluations of hyperfiltration at eight plants as a way to renovate composite wastewaters from textile finishing plants. The evaluations included performance assessment of different types of commercially available membranes, reuse of both renovated water and waste concentrates, and treatability of wastewater concentrates by conventional means. Both cellulose acetate and dynamic membranes, when used with the recommended pretreatment, proved feasible for wastewater renovation. When 90 percent of the feed was recovered, renovated water was satisfactory for reuse in scouring, bleaching, dyeing, and finishing. Successful reuse of residual concentrates containing significant quantities of dyes and chemicals was not demonstrated. Treatability of the residual concentrate by conventional processes produced effluent equivalent in quality to current plant discharges.

Kachel and Keinath (239) detailed a schematic flow diagram of a proposed textile printing wastewater renovation and reclamation system. The system provides for addition of a metallic coagulant and caustic to printing wastewaters for destabilization, for mixing and flocculation of the destabilized suspension, for particle aggregation, for flotation, for solid/liquid separation, for recycling of renovated water to printing machines, for addition of make-up water, and for solids disposal by incineration. Projected costs for three system alternatives indicate that the alternative which centers on the water reuse concept has distinct economic advantages over those in which treated wastewaters are discharged to a receiving stream.

Dyebath reuse was evaluated for batch dyeing of nylon carpet, nylon pantyhose, and polyester yarn (240). After an initial, standard dyeing of a batch of nylon carpet, water removed during the dyeing process was replaced and dyes were replenished. The recycled bath was then used to dye the next batch. Carpet and pantyhose dyed with reused dyebaths were considered acceptable as first-quality merchandise. Both single shade and multicolor dyeing of the polyester yarn with dyebath reuse resulted in acceptable coloration. In addition, there was an estimated savings in water and energy of 65 percent and 15 percent respectively for carpet; 90 percent and 35 percent for pantyhose; and, 81 percent and 41 percent for polyester yarn.

A new regenerative evaporation recycling system has been developed in West Germany for treatment and recycling of wastewaters generated in textile finishing operations (241). Evaporation is done under elevated pressure, and the distillate is of the highest purity. The residue is concentrated to 50 percent and incinerated to obtain dry salts as a residue. The extra cost of evaporation is minimal.

The IBK wastewater treatment and water recycling method, designed by IBK Koeppl of West Germany, has been used by textile manufacturers in response to increasing costs of water and wastewater treatment (242). Based on the principle of regenerating vaporization, the process treats effluents and recovers process substances. Steam produced during vaporization can also be used in heat-consuming equipment used in textile finishings. The high-quality distilled effluent can be used immediately in the power or water supply cycles. Additional treatment with activated carbon can qualify the regenerated water for other industrial uses. Heat recovery by the IBK recycling system lowers total energy costs for textile wastewater treatment.

Montgomery (243) described a water reclamation system at a textile dyeing plant. The system recycles 1.9 million gallons of water per day and can hold 80,000 gallons at one time. Two 20,000 gallon fiberglass tanks are fed by four working tanks of 10,000 gallons each. Chemical treatment and filtration are used to clean the water. The entire treatment sequence requires only four minutes, with another five to six minutes being required to feed the four tanks. Due to the short treatment interval, cleansed water re-enters the dyehouse at relatively high temperatures, thereby reducing final consumption and costs for heating dyewater.

Lusher (244) described water conservation measures taken in the linen industry to reduce waste discharges. Several methods to conserve water were reviewed, including repeated use of rinse waters. Chemical treatment and reuse seem to be the most effective way of disposing of industrial laundry wastewaters from the textile-cleaning industry (245).

Beaton (246) considered the applicability of ultrafiltration, a filtering process in which molecules of different sizes are separated by means of a finely porous membrane, to effluent of the wool and yarn industry. Wool effluent can be recycled or discharged to the sewer; however, yarn effluent ultrafiltrate cannot be recycled because the water contains dyes. Overall capital and operating costs were presented.

Water recycling and wastewater treatment adopted at a small-capacity cotton dyeing plant in East Germany has resulted in introduction of wastewater treatment by precipitation with ferrous sulfate for recycling in the flushing process (247). Hot water used for rapid driers also can be utilized in high-temperature equipment if it is softened. Boiler vapor condensates are also recycled.

Burke and Burke (248) discussed use of filtration, activated carbon adsorption and ion exchange for treatment of dye plant effluents and water recycling. The particular type of waste treatment required for dye removal is a function of the class of dye and its chemical composition. The particular system examined was designed for complete recycle of dyehouse effluent. The process described is capable of recycling about 80 percent of the water used in typical dye house operations. Operating and capital costs are such that this system pays for itself over a five to ten year period when compared with conventional treatment processes. Pilot plant evaluations are necessary to determine efficiency and economics of the system for a particular dyehouse wastewater.

The role of reverse osmosis in desalting and recycling textile dye wastewaters was investigated by El-Nashar (249). A pilot plant was constructed containing a precast membrane reverse osmosis loop and a dynamic membrane loop. Test results indicated that product water for each module could be recycled in the dyeing process; however, all membranes suffered from a tendency to become fouled with organic or inorganic colloids in the feedwater.

Lint content of wash water effluent, particularly from textile wet processing operations, has previously hampered attempts at recycling because of the difficulty inherent in removing lint effectively enough in a practical way to condition the water satisfactorily for reuse (250). A filter system is disclosed in which circulation of the liquid to be filtered is such that a predominant portion is continually returned through the filter unit to produce a filtered permeate amounting to 70 percent or more of the feed while also tending to clear the filter media continually.

Day (251) discussed the in-plant reuse of water from fortrel polyester fiber production. He described a new plant to be built when the water situation was such that reuse was necessary and economically feasible. The treatment scheme would consist of a plastic media trickling filter preceding the activated sludge unit. The activated sludge unit would be followed by polishing ponds, algae removal screens, and activated carbon. The recovered water would be used selectively in the plant, mainly as cooling water make-up.

Day (252) further described the water reuse program instituted at a fortel polyester manufacturing plant. The program consisted of: 1) pretreatment of cooling waters for removal of heavy metals; 2) in-plant modifications and additions to the existing system to increase treatment plant capacity; and 3) a post-treatment system for effluent polishing prior to selected reuse. Treated water was reused at a rate of 0.10 mgd.

Carrique and Jauregui (253) described a system installed at an Argentine textile mill to segregate the sodium hydroxide waste stream and reclaim the sodium hydroxide. The decision was made to install the system because high treatment costs for sodium hydroxide effluents and high replacement costs for sodium hydroxide itself made it more economical to reclaim the chemical then to replace it.

Jennings (254) conducted an exploratory investigation of recovery and reuse of textile size materials. Carboxymethylcellulose was dissolved from cotton warp with minimal amounts of water and the resulting solution used as the basis for further sizing formulation. One-third of the applied CMC could be removed from the sized warp obtaining a two percent solution. New formulations prepared from the solution gave satisfactory performance.

The waste handling system for the Fieldcrest Stokesdale, North Carolina, screen-printing plant produces no effluent (255). The complete waste flow is treated through extended aeration, chemical coagulation, filtration, chlorination, and incineration, then recycled back into production use.

Whittall (256) described a system for reclaiming laundry effluent for the textile industry. Used water from the washers flows over a heat reclaimer made of copper coils. Cooled water enters a settling tank via a series of filters which remove large insoluable matter. Water is then circulated through diffusing devices for oxidation of organic matter. Aerated water passes through additional filters and is then pumped through the heat reclaimer to the main hot water tanks. Thus, the volume of water discharge is reduced, heat is recovered, and the quality of the effluent is improved.

Eaddy and Vann (257) reported results of a demonstration project to treat effluent from two fabric finishing and dyeing plants. Permit requirements could be met with chemical additions ahead of multimedia filtration of biological effluents. Pilot plant studies were performed on recycled effluent for dyeing man-made fibers.

Brandon and Gaddis (258) reported on use of hyperfiltration to enable recycling of chemicals, water, and energy from textile finishing operations. Hot water could be recycled when purified with hyperfiltration. Polyvinyl alcohol recovery with 1-year payouts have been achieved.

Hyperfiltration and ultrafiltration are pressure-driven membrane processes which have potential for recycle of water, energy, and chemicals in wet finishing operations. Gaddis et al. (259) provided results of a study of energy conservation effects of point source recycle with high-temperature hyperfiltration in the textile industry. These workers observed that the reuse of water, energy, and chemicals can be best achieved if separations are applied to individual point-source streams rather than to total-plant mixed effluents.

Hog and Krogh (260) described various purification and regeneration techniques on wastes from textile and dyeing processes with respect to their performance and potential effects of recycling the effluent for use in textile processes.

Brandon (261) described a pilot hyperfiltration process used to purify and recover 75 to 90 percent of the wastewater from a textile dyeing and finishing plant. The use of ultrafiltration for removal of polyvinyl alcohol from textile mill wastewaters was developed by Aurich (262). Three years of operating experience indicate good and economic performance of the system in producing a reuse product.

Zawdzke (263) described results of laboratory-scale tests carried out on cotton bleachery wastes in an attempt to reuse the water. The activated sludge treatment used required added nutrients and resulted in 85-90 percent BOD removal. The water was clean enough to be reused for rinsing raw cotton after bleaching.

Due to acute water shortage and difficulties of waste disposal from textile dyeing plants in Israel, Rebhum, et al. (264) investigated renovation of wastewater for in-plant reuse. Separation of weak wastes from rinsing and wash operations was found to be feasible. By treatment of this wastewater in an aerated lagoon followed by neutralization, flocculation, filtration and adsorption, a colorless, turbidity and detergent free effluent was obtained meeting quality requirements for in-plant reuse. To maintain a constant TDS level and avoid excessive salinity build-ups, part of the effluent has to be withdrawn from the recycle system; however, at least 70 percent of the effluent can be recycled. Cost of treatment is comparable to that of fresh water supply.

Suchecki (265) reported on a wastewater treatment system built and operated on a pilot plant scale at a textile mill manufacturing indigo-dyed denim. The system, called WWTS/100, uses a special design for an electrodialysis unit to reduce pH and extract caustic and an electrodialysis cell and flotation unit to remove indigo dye. The system will recycle not only the expensive indigo dye but also the hot process water and caustic. When in full operation about 75 percent of the treated wastewater will be filtered, stored and reused.

Rüb (266) described the application of ion exchangers to water reuse in the textile industry. These should be used where small volumes of very high purity water would be required. Artyukhov et al. (267) described a wash water recycling system at the Cherkassk man-made fiber factory in which demineralization is accomplished by electrodialysis.

Samfield (268) reviewed major water uses in textile plants and identified some techniques available for conservation and reuse. Ray and Volesky (269) presented flow diagrams and descriptions of several textile wastewater treatment systems employing activated carbon as one unit process, to produce reusable water. Both granular and powered carbon systems were discussed. Saito and Yoshida (270) used a carbon column to remove dyes from wastewater with the effluent being recycled back to the plant. Laboratory tests using activated carbon to treat dye wastes indicated it was feasible to achieve a quality suitable for recycle (271).

Rhys (272) observed that adsorption on granulated activated carbon of dye wastes from a textile dyebath reduced effluent organic content and color to a level suitable for dyebath water reuse. Carbon adsorption operations in three textile dyeing plants were detailed. Single stage treatment with carbon was normally not sufficient to produce a good quality effluent that could be reused.

A bed of activated carbon is used to adsorb dyestuffs from the 500,000 gpd of effluent water from the dyehouse of a carpet mill, after which the water is reused (273). Jhawor and Sleigh (274) compared reverse osmosis and activated carbon for treating dyeplant wastes. Reverse osmosis also removed color and over 95 percent of the total dissolved solids lending the water suitable for reuse.

Porter (275) conducted a pilot-plant study on a textile waste stream. He found carbon adsorption to be a suitable method for regeneration of raw wastewaters for reuse. MaCrum and VanStone (276) discussed the successful use of granular activated carbon in the treatment of wastewaters from two textile mills. In both instances, treated wastewater is reused in normal plant operations.

A method for reclaiming textile wastes that contain dyes, wetting and scouring agents, caustic soda, and other chemicals was detailed by Pangle (277). By use of activated carbon, the Hollytex Carpet Mills in Southampton, Pennsylvania, has been able to reclaim 80 percent of the water used in the dyeing operations.

Phipps (278) described the textile wastewater renovation system at the Hollytex Carpet Mills in Southampton, Pennsylvania. The system, which consists of an activated carbon adsorber, has consistantly reclaimed 80 percent of the wastewater flow. Renovated water has been used for making up new dye solutions and for rinsing dyed carpeting. The system required only a 50 x 100 ft. (15.2 x 30.5 m) area.

Rock (279) discussed water use in woolen mills with special emphasis on possible reuse of effluents. Harker (280) also discussed reuse of effluents from wool processing with or without pretreatment. A patent was described by De Novion (281) for treatment of wool-scouring wastes and the return of the liquid back to production. The material is settled, steam evaporated and condensed, the settled matter separated, and the liquid returned to the process.

An apparatus has been described that continously treats wool wash liquid by utilizing a supplementary closed contaminant treatment circuit to increase efficiency and bulk (282). The closed cleaning system consists of a series of filters, hydrocyclones, heat exchangers, a thermal dryer, and conveyors.

French and South African patents (283, 284) have been issued for the design of wool process water purification plants. Separated water is recycled for reuse in the process.

Baloga et al. (285) reported on a study on the phenolic pollution problem resulting from manufacture of fiberglass. They concluded that reuse of the phenolic-resin-containing water was feasible. The water cycle of one machine in a fiber glass plant was closed, and the phenolic effluent was treated using a Delpark primary filter, a pressure diatomite filter, and fiber glass cartridge tubes. Results have demonstrated that: 1) reuse of phenolic resin containing wastewaters is feasible; 2) plant water usage is reduced by more than 50 percent; 3) diatomite filtration produced water of excellent quality; 4) product quality was not affected by using filtered process water in binder makeup; and 5) the high level of phenolic resin in the recirculated water has led to reduction in binder usage at a net operational cost savings.

The Johns-Mansville Company has developed a process for eliminating phenolic discharges by reusing phenolic wastes generated in the manufacture of fiberglass in the plant after filtering them to remove suspended solids (286, 287). Water use for the plant has been reduced more than 50 percent. Product quality has not been impaired by reusing filtered process waters. A net cost savings has been realized, attributed mainly to reduction of binder usage by the amount which is recirculated in the filtered water.

Amchem Products, Inc., Ambler, Pennsylvania, has been assigned a patent for a process for treatment of wastewater from a fiberglass manufacturing process (288). Treated water can be reused in industrial processes, thereby forming a closed cycle which is both more efficient and more economical. Steps are: 1) acidifying wastewater to a pH of 2.5-5.5 by addition of a non-toxic inorganic acid; 2) neutralizing acidified water to a pH of 7-9 by addition of a nontoxic inorganic base; 3) adding a flocculating agent to neutralized water to promote separation of treated water.

LEATHER TANNING

Tanneries are generally pollution-intensive industrial complexes generating large volumes of high-concentration wastewaters (289). Tanneries are not all alike. The basic design of procedures for hide preparation, tanning, and finishing vary rather widely according to the types of raw hides employed and the characteristics desired in the finished leather product.

At various stages in the conversion of raw hide to tanned leather, steps can be taken which will result in lower effluent volumes and reduction of the amount of solids, both in solution and as sludge, which needs to be discharged (290). Use of closed circuit tanning systems in vegetable tanning ensures that the minimum amount of tannin is lost by discharge into the effluent.

Bailey (291) made recommendations to the leather tanning industry in England and Wales for water conservation, reuse, and waste treatment. He suggested that the industry reduce the total throughput of water by better housekeeping, alteration of processes to use less water, separate cleaner fractions of the waste for direct reuse without treatment, and recycle after complete or partial treatment. Smaller volumes of concentrated wastes would facilitate the application of advanced treatment techniques. Several methods were proposed to reduce water usage. A table was presented showing possible recycle schemes for tanneries.

Wang (292) described three candidate physical chemical processing techniques for removing pollutants from tannery effluents which allow a greater bulk of the wastewater to be reclaimed as a useful water resource. Useful by-products may also be recovered. The techniques are specific surface adsorption processes: foam separation without additives, adsorbing colloid flotation, and adsorption-flotation.

Banks (293) proposed a tannery design to avoid or reduce potential pollution problems. Various chemical and biological treatment processes for production waste streams were discussed in terms of the different process steps involved. Reusing purified water and reclaiming chemical and metal resources were primary concerns. It was noted that this tannery design was a hypothetical one which assumed unlimited financial resources for implementation.

Perkowski (294) presented several reduction and reuse procedures for tannery wastewaters. He indicated that in some tanneries water use was reduced as much as 80 percent by institution of these procedures.

Hauck (295) reported on three methods of chrome recovery and reuse for utilizing the unspent portion of chrome in the tanning process: reuse through replenishment, direct reuse of the spent liquor, and chrome recovery. A review of past work in reuse is presented with reports of successful operation. Suggestions are given on possible modifications of the processes covered in the review. Direct reuse of spent liquor, in either the pickle liquor or as float in tanning is discussed. Several methods of chrome recovery are reviewed. Precipitation with an alkali will produce the chromium in a form suitable for reuse in a fresh liquor. Procedures are given for preparing the product for reuse. Basic requirements for reuse or spent chrome liquors were outlined. He indicated that there will probably be an upper limit to the number of recycles that can be used because of a buildup of impurities in the solutions.

Burns et al. (296) described a method for recycling chrome tanning liquors which is suitable for short pickling times. Spent chrome liquor is used as a base for the preparation of the pickle liquor for the following pack of hides or skins. Between each cycle, the spent liquor is reconstituted by addition of the full amount of mineral acid normally used in pickling together with a reduced amount of the desired masking agent.

Results of three small-scale trials on recycling of lime-sulfide unhairing liquors were reported in which the liquors have been recycled up to 27 times without deterioration in leather quality (297). All three trials produced no inferior quality leather. Advantages of reutilizing lime liquors are improved effluent quality and savings in water use.

Cortise (298) reported on the recovery of 60 percent of the total water used from spent tanning liquors. Unhairing wastes were neutralized, clarified, and subjected to biological treatment. As a final step, the water was disinfected and passed through ion exchange columns. Baskakov (299) neutralized pickling and spent chrome tanning wastes. The wastewaters, after neutralization and removal of the chromium, were suitable for reuse.

Simoncini and Del Pezzo (300) conducted pilot studies for recovering tannery wastewater for reuse. The procedure included mixing, flocculation with alum, and settling. Clarified liquid was mixed with about 20 percent makeup water and recirculated to the tanning processes. Buildup of soluble salts limited the number of recycles that could be used.

Vann Meer (301) conducted laboratory studies to evaluate means for reducing water use and wastewater volumes and found that combining the soaking and unhairing steps rather than discharging the soak water before starting the unhairing step reduced total organic waste load by 58 percent.

Davis and Scroggie (302) performed laboratory and full-scale tests on the feasibility of recycling spent chrome tanning solutions. Recycled chrome solutions were refortified with chromium oxide to give the desired chromium concentration. After three recycles, the liquors reached equilibrium and no further buildup of undesirable constituents occurred. It was estimated that cost of chromium could be reduced by 25 percent and the level of chromium in the effluent reduced substantially. Davis and Scroggie (303) investigated the reuse of spent chrome tanning solutions for preparing pickle liquor for suquents packs of hides. Chromium was reused for 12 cycles. It was postulated that the method could be used in normal tanning operations thereby reducing the costs of chromium as well as concentration of chromium in the effluents.

Weisburg (304) described steps taken by one tanner to reduce their wastes and the effects of these measures on the proposed treatment system. Since the major source of water is the dyeing operation, consideration was given to segregation, treatment and reuse. Unfortunately, none of the chemical coalgulants could produce an effluent satisfactory for reuse, primarily due to the color.

Niwa et al. (305) reported on treatment of processing effluents from the chrome tanning of upper leathers for reuse. Unhairing, tanning, and dyed fat liquoring wastewaters were screened, aerated individually and collectively coagulated, settled, passed through a contra-flow sand filter, and oxidized. Treated effluent was recycled to the original point-of-use and retreated 10 times. The recycling process was effective in controlling pH and reducing suspended solids, sulfide ions, and chrome; BOD, COD, and chloride ions were relatively unaffected by the treatment process. Chemical and physical properties and commercial value of the leather were not adversely affected by the reuse of recycled process waters. Recycling recovered

95-97 percent of the effluents and reduced raw water consumption by 91-92 percent.

Process modifications and wastewater reuse and treatment methods to reduce the total waste load discharged from a large side-leather tannery were investigated at the Pfister & Vogel Tanning Company in Milwaukee, Wisconsin (306). After laboratory and pilot-scale investigations, a system was designed for the recovery and reuse of chromium based tanning agents.

The Blueside Company plant at St. Joseph, Missouri, was designed to be pollution-free and equipped with the best available pollution control technology (307, 308). Both unhairing and tanning processes are performed at the plant. The plant uses only 1.0 - 1.5 gallons of water per pound of hide compound compared to 40-50 gallons per pound in some other tanneries. The wastewater treatment system consists of a holding tank from which solids are removed. The effluent is adjusted from pH 9.0 to pH 5.5 and aerated to remove sulfides. The airstream is treated with caustic to recover sulfide as sodium sulfide for reuse in the unhairing process. In addition, all wastewater streams are available for individual recycling.

Barber et al. (289) discussed reuse potential for treated wastewater at the Winchester, New Hampshire, chrome tan shearling tannery of the A.C. Lawrence Leather Company, Inc. Limitations of recycled water are noted. Estimated costs for effluent reuse are given.

PETROLEUM REFINING

The efficient and intelligent use, reuse, and recycle of water within refineries and petrochemical installations along with the final disposal of waste residuals into the environment present a growing challenge to management (5).

It has been estimated that the petroleum and petrochemical industry of the U. S. would require in excess of 12 billion gallons of water daily for once-through usage (309). Because of reuse-recycle, makeup requirements are slightly in excess of 20 percent of this amount with cooling water recycle accounting for approximately 90 percent of the reused water. Recent developments in cooling tower and boiler equipment and the application of chemicals have enhanced the possibilities of reuse-recycle.

A review of water reuse, water quality requirements, and current treatment practices for water from the petroleum refining industry was given by Evers (310). Requirements vary depending upon the future use of the recovered water. Tables illustrate the quality characteristics of untreated cooling waters, water use and reuse by refinery classification, raw water and reused water for steam and processing, guidelines for boiler feed water tolerances and cooling water tolerances, water quality requirements of water at point of use for the petroleum industry, and treatment systems used for refinery raw waters.

Weil and Jackson (311) presented data on water use and reuse practices of petroleum refineries. The data were gathered by an industry survey conducted by API. Completed questionnaires were submitted by 94 refineries (4 Canadian and 90 U.S.) with total crude capacity of 6,346,000 barrels per day. These refineries represented 55 percent of the U.S. total crude capacity and 18.5 percent of Canadian capacity. The data are summarized by refinery operational complexity. Average total water used, raw water used, and water reused are reported for each classification. The data are further divided to show use and reuse for cooling, processing, and steam production.

Johnson (312) stated that the petroleum industry has the highest reuse rate among the top 10 industrial users of water. The reuse of water for process cooling is by far the largest reuse application of water. Recycling of cooling water has always received considerable attention by refineries because it represents as much as 90 percent of refinery water usage (313). Since the principal water requirement in refineries is for cooling, use of fresh water is minimized by recirculating the water over cooling towers and by substituting salt water wherever possible (314).

Some degree of effluent water reuse is practiced by most refiners (33). Water reuse is usually limited to use of stripped sour water for salt washing in crude oil desalters. Recent restrictive regulations and limited freshwater supplies have emphasized the importance of reusing effluent water. This paper describes an oily steam system designed for a 200,000-barrel-per-day refinery to practice reuse of process condensate. Discussions cover reuse of various refining streams and processing schemes for a conventional water system, an oily steam generation system, and a zero discharge system.

A number of opportunities exist in industry for the application of sequential industrial reuse and recycling (5). On a volume basis, recycle of cooling water is one of the most widely used practices. On an average, about four percent of the water is lost during one cycle through a cooling tower. Steam condensate provides a high-quality water, and this source of water can be recycled.

The possibilities for wastewater reuse as a measure of water conservation in an oil refinery were considered by Garcia (315). Klooster and Beardsley (316) outlined water conservation measures for modern oil refineries. The first step necessary to reduce waste effluents is to segregate waste streams according to the degree of treatment required. Sour condensates produced in crude units and hydrocrackers can be reused as crude condenser wash water, desalter wash water, and/or recycled water for the hydrocracker after simple steam-stripping to remove ammonia and hydrogen sulfide. High mineral, nontoxic salt concentrated streams which are not contaminated with organics can be reused for various process requirements after desalination and/or mechanical evaporation. Some waste streams containing non-hardness and non-siliceous mineral salts, but otherwise contaminated with organics, may be used as cooling tower make-up.

Milligan (6) presented several schemes for reuse of refinery wastewaters, while indicating the need for demonstration tests to accomplish potential reuse objectives. Griffin and Goldstein (317) discussed two successful experimental programs conducted as part of studies involving refinery wastewater reuse. These studies permitted the development of bases for defining optimum approaches to water use and reuse. Refinery effluent water reuse presents a unique opportunity for utilization of waste heat for the reduction of wastewater volumes because the process technology used for evaporation can use this low grade waste heat as an energy source. Increasing present day and future energy costs increases attractiveness of the approach for those situations where it is needed.

With the degree of treatment required for refinery wastes, recycling has become an important and feasible practice that must be considered by industry in any proposed solution to an existing waste problem (313). Basic fundamentals associated with recycling were examined. These authors feel that technology to achieve complete reuse in the refining industry is available, and with increasing costs for purchases of fresh water and for waste treatment, the implementation of an overall water reuse program will be justified.

Water reuse in a refinery to be effective and economical requires a thorough analysis of the quality of wastes at every point in the refinery with a concurrent establishment of the quality of makeup required for water utilizing processes (318). Selection of appropriate chemicals for corrosion and deposit control, appropriate equipment and material of construction specifications, all together can allow a local reuse of water with minimum treatment within sections of the refinery. The end result is greatly reduced volume of highly concentrated waste amenable to total evaporation and disposal at acceptable costs if such is ultimately required.

Process modifications, in-plant control practices, and recycle-reuse of wastewaters have resulted in decreased water requirements within the refining and petrochemical industries (5). However, to exploit all reuse opportunities, some form of treatment is required. This article examines interrelationships between treatment and reuse and presents a format for selecting the optimum process for reuse.

Through the application of available advanced waste disposal processes and equipment, it is possible to achieve near ultimate disposal of petroleum refinery and petrochemical wastes (319). Simultaneously, it is possible to upgrade the quality of wastewater to degrees commensurate with process requirements or pollution abatement regulations.

Meyers and Mayhue (320) discussed advanced waste treatment processes applicable to the petroleum refining/organic chemical industry. It is not expected that any one process will be universally applicable.

A very high degree of wastewater treatment is a necessity for renovation of wastewater for deliberate reuse. Huang and Hardie (29) reported on a study designed to investigate the applicability of using physico-chemical processes for purifying refinery wastewaters with emphasis placed on explanation of treatment efficiency and performance characteristics.

In newly constructed petroleum refineries, full integration of in-plant procedures and multistage wastewater treatment is combined with reclamation and reuse of purified water (39). This results in considerable progress in pollution abatement and a drastic reduction of clean water intake requirements. Collecting wastewaters separately, according to their subsequent treatment, and employing pretreatment methods such as evaporation, stripping of sour water condensates, and equalization of flow and strength of wastewaters, improves product recovery and reduces waste load. Treated wastewater is used as makeup water for recirculation cooling systems, and specific water consumption and wastewater discharge per production unit are reduced.

In the long run, the success of effluent reuse will be predicated on producing equipment capable of tolerating higher concentrations of contaminants, with the end result approaching infinite recycle and inplant concentration of pollutants (309). In other words, effluent treatment should be avoided by using process units as contaminant concentrators and employing in-plant treatment to maintain high recycle rates while minimizing blowdown. To optimize this scheme, makeup water treatment processes must be consistent with the philosophy of reuse-recycle.

To minimize refinery effluent water treating costs, it is necessary to maximize inplant water reuse and treatment (321). Inplant schemes employed to reduce wastewater and, in some cases, reduce contaminant concentration were discussed. Prior to any wastewater treatment system modification, refinery management should first look back to the process and determine what can be done to reduce wastewater flow and contaminant concentration.

Milligan (6) summarized ideas for the reduction of water use and for reuse of wastewaters in the petroleum refining industry. He suggested a step-by-step progression from BPT to BAT and to zero discharge for existing refineries. He noted, however, that some of the concepts proposed may not be applicable in specific cases. Order-of-magnitude costs of $6 million and $10 million respectively, have been estimated in 1975 dollars for the modifications and additions required in changing a representative 100,000 bbl/day refinery treatment system from BPT to BAT to zero discharge treatment technology. These costs indicate the large capital investment required to meet the 1983 and 1985 goals of the Federal Water Pollution Control Act Amendments of 1972. Maximum reuse of wastewater must become a normal operating practice if these goals are to be achieved at any practical cost.

The goal of zero discharge will be a difficult and expensive one to attain for oil refineries. Porter et al. (322, 323) described one approach to the zero discharge goal for a "typical" existing oil refinery. A 100,000 barrel/day integrated oil refinery was defined for use in this study. The refinery was assumed to have most of the typical large scale oil refinery processes with wastewater treatment typical of that required for BPT. The zero discharge requirement alters the usual priorities and constraints governing the design of waste treatment systems and forces consideration of the refinery's whole approach to water management, the use of chemicals, and, to some degree, the hydrocarbon processing steps. These workers presented a list of several general principles which, if given attention when considering the possibility of operating a refinery under the zero discharge constraint, can help to lesson costs.

The American Petroleum Institute, in a monograph titled "Water Reuse Studies", termed complete reuse of refinery water technically feasible (102) The study notes that capital and operating costs appear favorable for complete recycle, although engineering concepts must be demonstrated in a full-scale refinery. Findings place a high priority on pretreatment of utility water to permit high cycles of concentration of cooling water. The report states that zero discharge may actually be desirable.

Boris (324) reported on use of activated carbon adsorption to treat refinery wastewater for use as cooling tower makeup. The tubuler activated carbon system followed chemical coagulation and sand filtration.

Brady (325) discussed the effectiveness of in-plant measures in reducing wastewater discharge problems in the petroleum refining industry. Such measures were discussed in terms of engineering design considerations, process design modifications, recovery and utilization, local pretreatment or disposal, and operational control. Examples of ways in which pollution could be reduced by these methods were given.

Lieber (326) discussed reduction of water usage, inplant pretreatment, effluent segregation, and effluent treatment at a new refinery. Carnes and Wood (327) discussed refinery wastewater treatment and reuse. In-plant treatment and recovery practices were reviewed, and effluent treatment systems were discussed. Primary, intermediate, and tertiary treatment systems were outlined. Special emphasis was placed on water reuse.

Thompson (328) discussed improvements in processing and housekeeping techniques designed to upgrade the quality and reduce the volume of refinery effluents. A proposed wastewater treatment and recycling system was presented.

Bush (329) described various treatment processes available to treat refinery wastewater for reuse and to produce acceptable effluent qualities. Unit processes were categorized as primary, intermediate, or secondary/tertiary. The choice of one or more of these stages depends upon the quality of the raw effluent and the required pollutant reduction.

Many refineries practice a combination of recycle and step-wise reuse that also performs waste treatment functions (5). In these facilities, selected waste streams containing low dissolved solids are first treated by removing the oil and then used as makeup water for the refinery's cooling towers. This practice not only reduces refinery water consumption but also accomplishes high removal of BOD and phenolic type compounds.

The refinery water system has a number of streams which cannot be reused without a significant investment in capital and operating costs (33). These streams do not lend themselves to reuse because they are high in dissolved solids. Removal of these dissolved solids is expensive, and disposal of the solids in an environmentally acceptable manner may also be costly, depending on plant location. These streams are:

1. Blowdown from the cooling tower;
2. Blowdown from steam boilers;
3. Effluent from the desalter; and
4. Regenerant from water ion exchange facilities.

The schemes discussed show various methods of recovering effluent streams for reuse. Streams high in dissolved solids do not lend themselves for reuse without extensive processing.

In order to achieve zero discharge, dissolved solids must be removed from the recycle stream to prevent corrosion, scaling and other damage to cooling tower, heat exchange, and steam generation equipment (309). Apparently, only three processes are suitable candidates for the purpose of demineralization, i.e. reverse osmosis, electrodialisis, and ion exchange.

Treated effluents may be acceptable for reuse within the refinery; however, something must eventually leave the system whether in the form of a liquid blowdown, brine, or dry solids (309). Common practice has been to maintain a recycle system in economic balance by wasting a portion of the recycle. However, as water becomes more scarce and disposal criteria more stringent, additional treatment will be employed to reuse the blowdown or remove the contaminants from the makeup supply.

Mohler and Clere (330, 331) described a process which successfully handled oil refinery wastewater and conserved fresh water. The system reduced water consumption to as little as 17 gallons per barrel of crude oil compared to the national average of 214 gallons per barrel of crude. The process evolved from experiments in the Toledo Refinery of Sun Oil Company based on the use of cooling towers to provide bio-oxidation of phenolic materials while using the waters for conventional process cooling. The mechanism, design, operation and maintenance data are given. Additional reuse from operation of the sand filter system will reduce consumption below 10 gallons per barrel of crude.

The Chevron wastewater treatment process treats refinery wastewater and converts it into three valuable products: high-purity hydrogen sulfide; pure ammonia; and treated water for recycle or discharge (332, 333). Operation of the process is discussed in detail. Economics of the process are very dependent on the feed concentration; a more concentrated feed requires a less expensive plant.

A patent has been issued for the Chevron process to produce recycle water and to separate ammonia and acid gas from wastewater (334). Wastewater is passed through an acid gas-ammonia stripping column to produce a recycle water stream and an effluent gas stream of acid gas, ammonia, and water vapor.

Sour water stripper bottoms (SWSB) are essentially distilled water and can be reused as desalter water, process wash water, cooling tower makeup and/or boiler water makeup (335). If hydrogen sulfide and ammonia are properly removed, SWSB are ideal desalter water. Problems with use as desalter water include changing ammonia concentrations, cyanides which will transfer to the oil phase in a desalter, and formation of ammonium naphthenate soaps due to an incorrect pH. SWSB have been used as process wastewaters in catalytic cracker spray systems and overhead condensers for FCC main column and crude units with few problems. Results of using SWSB as cooling tower makeup normally depend on stripper efficiency, cooling water treatment, and controls. Reuse of SWSB as boiler makeup depends on existing external treatment equipment. Problems include corrosion and deposition of sulfides, heat transfer and under-deposit corrosion attack from iron sulfate, ion exchange resin fouling and boiler foaming and carry over from oil contaminants in the stripper bottom, and ammonium bicarbonate deposits from the presence of ammonia.

Gloyna et al. (336) described a system designed to treat liquid wastes from oil refineries and produce a salable product. Finished products from the system are cresylic acid and sodium sulfide solutions.

Grutsch (337) described methods used for reducing or eliminating petroleum refinery wastewater discharges. Waste streams were identified that could be segregated by quality characteristics for reuse in generation, or cooling, or requiring extensive further treatment. Finelt and Crump (338) presented a procedure for determining the optimum system for reusing water in preparing cooling tower process and boiler makeup water in petroleum refineries.

Several refineries and petrochemical plants, particularly in the western United States, reuse municipal effluents as makeup (309). The direct reuse by a refinery of a wastewater from an external source is generally applicable only if the supply is dependable, reliable, accessible, and economically competitive with freshwater sources.

Mayes and Gibson (86) discussed an oil refinery's experience with using reclaimed municipal wastewater for 15 years. Economic data were presented to aid in making decisions in the choice between using sewage effluents and other sources of poor-quality water. Foaming, corrosion, and excessive gypsum content of the water were the only major problems encountered.

Denbow and Gowdy (339) detailed wastewater reclamation programs at the Humble (Exxon) Oil Refinery in Baton Rouge, Louisiana. Several in-plant modifications were made in the late 1960's and early 1970's to eliminate wastewater discharges. Among these modifications was the reuse of some process wastewater for cooling water.

Kirby (340) discussed water conservation at the Lake Charles Refinery-Petrochemical Complex of Cities Service Oil Company. Each of the three major plants in the complex has a separate biological wastewater treatment system. Designs of the systems for providing secondary treatment differed according to specified requirements in each plant. All of the butyl rubber plant effluent is reused as refinery cooling tower makeup. Kirby reported that water reuse was being expanded throughout the complex.

The 23 MGD wastewater treatment plant installed at the AMOCO Oil Company refinery at Texas City, Texas is the most sophisticated refinery effluent water quality control system in the U.S. (341). The plant treats wastewater and stormwater from the refinery and two chemical plants. Facilities include: storage for storm flow; emergency spill basin; preservation; chemical destabilization and filtration; two-stage activated sludge; and filtration. The quality of the treated water will be high enough to allow it to be reused, thus reducing the freshwater demand of the refinery and chemical plants. The facility incorporates all the elements recommended by EPA at the BPT level of treatment plus unique, proprietary process design and operating features by AMOCO.

Gulf Oil Canada Limited's oil refinery at Point Tupper, Nova Scotia is being successfully operated with the help of technologically advanced engineering innovations (342). Features of the plant include substantial fuel savings, increased process efficiency, low excess air cooling, extensive pollution control for air and water, and all-electronic instrumentation and operation. Total air cooling of the plant has eliminated the need for cooling towers and the use of toxic chemicals associated with cooling towers. The amount of fresh water required has also been reduced. The wastewater treatment process includes extensive water reuse.

The water budget and complete water cycle of the Mobil Oil Refinery at Woerth, West Germany was described by Siebert (343). Hydrogen sulfide and mercaptans in process waters are separated in an acid water stripper with the purified wastewater being reused for the desalting of crude oil.

Mobil Oil Corporation's East Chicago, Indiana, refinery has been reusing water in various ways for more than 30 years (344, 345). Sulfides and ammonia are removed from process wastewater in a sour water stripper. A dissolved air-flotation unit removes oil and suspended solids. Treated wastewater is then reused for cooling tower makeup while cooling tower blowdown is used for pump-gland systems. Stripped sour water is reused as crude desalter wash water. One of the major innovations for water quality improvements at this refinery is the reuse of treated wastewater in cooling towers. This practice was instituted in October, 1969.

Rose (346) discussed the use of cooling towers to permit recirculation of 40,000 gpm of water for cooling and condensing operations at the Sohio Refinery, Lima, Ohio. Recirculation of cooling waters conserves water, reduces the volume of waste to be treated, and minimizes loss of pollutants. Sodium hydroxide solutions used in several treatment operations are regenerated for reuse or sold. Separate sewer systems allow recovery and reuse of lost chemicals. Water used in the high pressure hydraulic coke cutter is recycled. Sulfides are removed in steam strippers, and phenolic waters are used as makeup in the crude oil desalting process.

Eygenson and Ioakimis (347) outlined basic trends in wastewater treatment in the petroleum processing industry in the USSR. Efficient biological treatment plants are available at most of the petroleum processing plants. Recycling of the industrial water following biological purification is envisioned.

ORGANIC CHEMICALS

Current practice in the organic chemicals and plastics industry is to treat a raw fresh water supply to a rather high degree of purity, utilize it in utility and process operations, recycle appropriate portions for reuse, and treat the balance for discharge back into the environment according to appropriate effluent standards (348). If the national goal of zero pollutant discharge is realized, water reuse will be a natural course of action. Of course, there will always be makeup water required to offset losses due to evaporation, leakage, certain water treatment processes, and processes involving the chemical combination of water. There are many economic and technical hurdles to be crossed before reuse can be generally applied, however.

Existing secondary wastewater treatment facilities in the organic chemicals manufacturing industry are, in general, of the biological type which produce effluents not meeting the water quality criteria required of makeup water for most heat exchange systems; nor is the product suitable feed for typical water treatment facilities (349).

In-plant reuse of process water and recirculation of cooling water is now common practice in many petrochemical plants (350). Water reuse is often one of the most effective and economical means of decreasing waste discharges from a petrochemical plant. In addition to reducing water costs and waste treatment costs, water reuse increases the flexibility for plant expansion. Small quantities of concentrated wastes produced by reuse are easier to handle than larger quantities of dilute wastes, and the plant benefits by more freedom from upstream users (351). Potential applications of water reuse include the utilization of poorer quality cooling and boiler water and also the reuse of contaminated streams in stripping operations (352).

Feasibility studies are needed to determine the capability of petrochemical plants to reuse more of their wastewaters (350). The authors discussed physical, chemical, and biochemical treatment of petrochemical plant wastewaters.

Implementation of complete water reuse in an integrated petrochemical plant will be expensive and requires significant technological advances (348). This survey of water use patterns points up a key problem in implementing water reuse in many petrochemical plants - that is, discounting the once through cooling water, the large volume water users (boiler feedwater and process water) demand premium quality, essentially organic-free water. This level of quality will not be met by simply subjecting present-day secondary effluents to conventional clarification and demineralization operations. A schematic flowsheet of a complete wastewater purification system that will be required to meet zero discharge effluent standards or to provide high purity water for recycle is presented. Estimates of investment and operating cost to achieve complete water reuse in the subject plant are given.

A study was conducted by Union Carbide, Inc. to examine costs and water quality resulting from a best state-of-the-art process for treating wastewater from the organic chemical manufacturing complex in Puerto Rico. Effects of residual contaminants in renovated water used as boiler or cooling tower makeup were also examined (41). Tertiary treatment included coagulation, flocculation, clarification, filtration, granular activated carbon adsorption, and pressure filtration. The tertiary treatment plant produced water of a quality sufficient for use as high-pressure boiler feedwater. Water of high enough quality for use as cycle cooling water was produced with fewer unit operations. Use of renovated wastewater as cooling or makeup water required construction of heat exchangers to maintain satisfactory corrosion and heat transfer characteristics.

A wastewater reuse pilot plant was installed in the Union Carbide, Inc. organic chemical manufacturing plant near Ponce, Puerto Rico (3, 349). Reuse feasibility was demonstrated in two carefully controlled modeled heat transfer test loops. The primary objective was to demonstrate the quality of water each step of the treatment could be expected to produce from an organic chemical plant secondary wastewater treatment system and to determine operating costs when this water is renovated for reuse as boiler feedwater or cycle cooling water makeup.

The total annualized cost of producing boiler feedwater through a renovation system consisting of reactor clarifiers, carbon adsorption, pressure filtration, reverse osmosis and ion exchange would be approximately $\$2.00/m^3$ (\$7.50/1,000 gal.) in 1978, not including primary or secondary treatment costs or facilities for the handling and disposal of waste brines and sludges (349). Waters of lesser quality than feedwater could be obtained at significantly reduced costs for use in low pressure steam systems or as cooling water.

Sidwick (353) discussed the characterization and development of a treatment process for reuse of wastewater from an organic chemicals plant. Units included oil separation, stripping tower, biological treatment, sand filtration, activated carbon, and, as necessary, reverse osmosis.

Schroff and Sheth (354) discussed various aspects of the recovery and reuse of water and chemicals from wastewater produced during the manufacture of various organic chemicals in India. Water and waste management practices were discussed with respect to their cost-benefit ratios. Case studies on the recovery and treatment of liquid and gaseous wastes were presented for an oxalic acid plant and a malathion plant. Limitations on the reuse of fully and partially treated industrial wastes were discussed.

Banerji (89) described a combined biological-physical/chemical treatment system providing a reuseable water at a chemicals and plastics plant in Bombay, India.

The Pervomaisk chemical complex in the Ukraine has become the first industrial complex in the USSR to operate with a closed-cycle water system (355). Because mixing of effluent streams resulting from various manufacturing processes may produce complex reactions, wastes are treated separately in five streams, and on-site reuse of wastewater is maximized. Ion-exchange resins are used to treat wastewater prior to reuse. Adoption of the closed-cycle water system has reduced water consumption at the plant to three percent of its previous level.

Ricci (356) described a new pilot-scale system that renovates organic chemical-laden wastewater for reuse in manufacturing operations. The system combines activated sludge treatment, physical/chemical treatment, reverse osmosis, and primary and secondary ion exchange. Another pilot unit has demonstrated the effectiveness of ultrafiltration for concentrating dilute latex wastewaters for reuse.

A pilot plant of 100 gallons/minute capacity was constructed and operated for one year by Dow Chemical Company to demonstrate the feasibility to remove and recover phenol and acetic acid from an 18 percent sodium chloride brine by adsorption on fixed beds of activated carbon (357). Purified brine was used for production of chlorine and caustic soda. Tests of the purified brine showed it to be equivalent to pure brine. Desorbed phenol was recycled to the phenol manufacturing plant. Projected net costs of purifying this waste brine for reuse were given.

Petrochemical wastewaters containing relatively high concentrations of salt and refractory organics were selected to study their feasibility for total recycle (358). A combination of reverse osmosis and electrodialysis was operated as a hybrid system using pretreated wastewaters to produce reusable water and a concentrated brine. The combined system is not considered economically feasible when applied to industrial wastewaters containing relatively high concentrations of salt.

Reuse of boiler feed and cooling water is a common practice in the polymer industry (359). The author focused on reuse of process water. In considering process water, it must be pointed out that water quality is of particular concern. Water quality has an important bearing on chemical and physical properties of the polymers made. To minimize capital investment and operating costs toward maximum reuse of process water, steps should be taken first to reduce current uses of process water and chemicals. A concept for maximum use of process water was presented; however, total use of process water has not been achieved in the proposed scheme. This is in spite of addition of costly advanced treatment techniques. A means for disposal of concentrated brine from the desalting unit has to be found.

The Dow Chemical Company's Dalton, Georgia plant uses alum coagulation and sedimentation to remove synthetic rubber particles from process, coolant, and wash waters used in the manufacture of styrene-butadiene latexes (360, 361). After clarification, the water is collected in a 9 million gallon reservoir for subsequent reuse and fire protection.

A 14-effect vertical tube evaporator was built for recovering water from a waste stream at a synthetic rubber plant at Odessa, Texas (362, 363). The plant has a nominal rated capacity of 40,000 tons per year of butadiene-styrene type synthetic rubber. The waste stream contains 3500 ppm dissolved solids and organics in excess of 100 ppm. Water having no organics and a very low dissolved solids level was recovered for use in the manufacturing process and also for cooling tower and boiler makeup. Engineering data to improve design of future plants and costs for water reclamation were presented. Corrosion of the heat exchange surfaces made continous operation for long periods impossible.

Evaluation of a full-scale wastewater recycle and reuse system was included in a report by the B.F. Goodrich Chemical Company on wastewater treatment facilities for a polyvinyl chloride (PVC) production plant that includes emulsion, suspension, and bulk polymerzation processes (364).

An efficient, nonpolluting fixed-bed ethylbenzene process utilizing a solid, non-friedel-crafts catalyst to alkylate benzene with ethylene has been developed (365). After preheating and vaporization, fresh and recycled benzene combines with an alkylaromatics recycle stream and fresh ethylene. The process has been tested successfully in a 40 million pound per year plant and is now ready for commercial use. The process avoids pollution problems, reduces catalyst consumption, eliminates the need for highly-corrosion-resistant construction materials, and recovers more easily the heat of reaction.

Malakul (366) provided a system for reclaiming solutions of waste chemicals such as ethelene glycol. Water in the ethelene glycol is distilled or evaporated off at temperatures below the boiling point of glycol. The system includes two or more interconnected evaporating stages, each having a heating coil. The last or final evaporating stage is provided with an aqueous solution sensing loop for removing portions of the reclaimed solution at predetermined levels and is provided with a water sensing station for removing condensed steam or returning contaminated water to the input of the system.

Gadjiev and Chian (367) conducted a laboratory study to evaluate potentials of various physical-chemical processes in treating oily wastes originating from a large aerosol manufacturing plant. Two overall approaches or alternatives were presumably available to the plant for dealing with its wastewater problem: 1) to "completely treat" its wastes and either discharge them directly into the receiving stream or reuse them in the plant; or 2) to pretreat these wastes and discharge them into the municipal sewage system for final treatment. The second alternative was negated by costs associated with flow control and an already overloaded municipal treatment plant. The reverse osmosis process showed promise as a method for removal of both organics and inorganics from aqueous solution, thereby, producing an effluent suitable for in-plant reuse. Chemical coagulation followed by sand filtration appeared to be the most promising process for pretreating wastewaters prior to the reverse osmosis process. A flow diagram of the proposed treatment system was given, and estimated capital and operating costs of a 100,000 gpd. treatment system were presented.

Kuo (368) discussed problems of separation and concentration of organic solutes in aqueous solution and proper use of reverse osmosis in preparing such waters for reuse. He noted that not all organic solutes can be removed by reverse osmosis; in fact, some may be concentrated in the product water.

Thompson et al. (369) reported on a study designed to develop a simple, structural economic basis to evaluate in ethylene production, the effects of variation in policy, particularly water policy, on the use of water and the cost of producing ethylene. The report includes: 1) a description of a linear economic model of water use and waste treatment for a representative ethylene plant; and 2) an analysis of the effects of variation in certain policy variables on the use of water and the cost of producing ethylene. A flow chart identifies how water is used and how wastes are treated in the representative model plant. The chart identifies the decision possibilities available at each point of water use and reuse.

Waste from the manufacture of food grade, fatty acids and glycerides, and derivitives was treated in two separate systems (370). Water from the glycerine evaporators vacuum system was used directly as cooling tower makeup water. Water from the vacuum system of the fatty acids stills was treated by dissolved air flotation before recycle to cooling towers.

Kakushkin (371) reported on the use of a closed cycle at a biochemicals factory. After biological treatment, treated liquid was reused. An example of water reuse in a cresylic acid plant was presented by Burnham (23).

For a realistic approach to water reuse in petrochemical plants, a coordinated attack is needed, utilizing all available technologies where appropriate (372). In contrast to experience with domestic secondary effluent, activated carbon treatment of petrochemical wastewater does not produce a reusable water, essentially free of organics, even in larger sized adsorption systems. Myers and Mayhue (320) observed that activated carbon may pave the way to the use of other waste treatment processes and their incorporation into the total treatment scheme for water reuse.

A carbon adsorption plant to recover p-cresol from a wastewater effluent stream by adsorption on granular carbon, followed by chemical regeneration was piloted, designed, and constructed to meet air pollution standards (373). More than a year's satisfactory operation was reported. Not only were emission standards reduced to exceptable levels; but enough p-cresol was recovered to pay back installation costs in less than two years.

Christenson and Conn (374) described an advanced wastewater treatment system for petrochemical waste generated from a large sour gas plant. Wastewater was renovated to near drinkable quality using a treatment sequence of oil removal, biological treatment, chemical clarification, mixed media filtration, and activated carbon adsorption.

The nature of waste from pharmaceutical manufacturing facilities is dependent upon the chemical processes involved so that a decentralized approach to waste treatment and potential water reuse can be applied regardless of plant size (375). Segregation of waste streams plus decentralized treatment must be applied in a stepwise manner to implement a sequential long range plan to achieve zero discharge by 1985. Chemical valves should be recovered, if feasible, in order to permit reuse of the available water as makeup to the plant supply.

An effluent treatment plant for liquid wastes from a pharmaceutical chemicals factory in Northeast Italy was described by Cominetta and Summers (376). The plant was designed to achieve a water quality sufficient for complete recycling and reuse. Treatment facilities incorporate chemical, physical, and biological treatment processes. After removal by sedimentation of the solids and passage through sand filters and activated carbon units, effluent from the activated sludge unit is suitable for reuse in the factory.

The North Chicago Plant of Abbott Laboratories uses a systems approach to prevent water pollution (377). The objective is to minimize total pollution which results from production operations, natural occurences, and accidental spillage. Included among many different types of treatment operations are the recovery and recycle type. More than 75 percent of the potential waste streams, expressed on a BOD basis, are processed through recovery systems.

A multi-evaporation process, called the Carver-Greenfield process, has been used in the food processing industry successfully and is now finding application in the recycling and ultimate disposal of chemical wastes (378). Since tighter environmental standards have made the cheaper methods of disposal ecologically unsound, the Carver-Greenfield process, previously considered too costly, has become a viable alternative. Application of the process to two types of wastes streams was considered: a pharmaceutical manufacturer and an oil refinery. Basically, the system consists of three components - a fluidizing tank, evaporator and centrifuge.

INORGANIC CHEMICALS

Because of increased costs and stricter discharge requirements, the average plant water recycle-rate for chemicals and allied products is projected to be 27.1 by the year of 2000 (102). Most of the increase will result from modifications to cooling-tower recirculation systems, but a lot will come from a variety of measures designed to collect and recycle all water within the plant and limit discharges as much as possible.

Complete water reuse in a chemical manufacturing plant can be both a conservation measure and a method of pollution control (19). There are many problems, however, associated with complete reuse that must be overcome before it can become a practical application in most plants. Essentially all plants use some form of recycle now, and with the advent of practical technology the degree of recycle will be expanded.

Brymer (19) discussed the design of treatment processes for reclaiming wastewater in the chemical manufacturing industry. The selection of treatment processes for upgrading wastewater to a quality suitable for reuse was described by an illustration that involves categorization of wastewaters by quality.

For selective plants use of innovative process engineering can achieve in-plant abatements which will result in zero discharges from the facility (379). Application of process engineering studies have been successful at alum plants to effect zero discharge. Also reported are process evaluations in progress to eliminate discharges from both phosphoric and hydrofluoric acid facilities. Steps necessary in the process engineering program have been defined and application of this technique discussed.

Reiter and Stocker (380) reported that Allied Chemical has eliminated waste discharges from an alum plant, and were currently evaluating techniques for achieving zero discharge from its phosphoric acid and hydrofluoric acid facilities. A two-pond containment system was installed, pumping wastes to the first lagoon where suspended solids are removed, then to a second lagoon which functions as a clear well. The water goes back into the process as make-up for subsequent batches, completing a closed-loop operation.

Grover (381) described a waste stream management program adopted by the Dow Chemical Plant in Pittsburg, California. The first phase of the program identified sources, uses, and sinks of water in the plant. The next phase attempted to define a balance between the three categories which would achieve the zero discharge goal for aqueous effluents. The water management plan in operation at the plant since 1975 utilizes three main water subsystems including a cooling water loop, a recycle water loop, and an aqueous chemical sewer. A series of solar evaporation ponds provide the primary means of wastewater disposal. Although the system is not considered technically feasible for areas of the country having lower annual evaporation rates, the waste management system is recommended as a means of minimizing overall discharge volumes.

Eli Lilly and Company has designed and built a fermentation plant at Clinton, Indiana for total environmental security, regardless of the cost involved (382). Recoverable chemicals will be recovered regardless of costs. All waste streams will be treated individually. Ninety percent of the total water used in all processes will be recycled.

Gaydos and Rogers (383) presented a solution for wastewater disposal at a factory which manufactures five chemicals and requires substantial quantities of comparitively pure water. The proposed solution involves a multi-stage flash distillation unit and a crystallizer. The distillation unit recovers 88 percent of the water content and returns ultrapure distillate to the chemical plant. Blowdown from the distillation unit proceeds to a crystallizer which recovers the balance of the water content. Solids discharged from the crystallizer are centrifuged, dried, and packaged for sale as highway de-icer. The income in dollars per day and the quality of valuable by-products recovered are presented.

Mississippi Chemical in Pascagoula, a manufacturer of sulfuric acid, phosphoric acid, anhydrous ammonia, and nitrogen, phosphorus and potassium mixed fertilizers, has installed a 10-unit closed water treatment system (384). A discussion of the treatment system is presented.

All process water at the Diamond Shamrock Company Chrome Chemicals Plant at Castle Haynes, North Carolina, is recycled (385). Treated wastes are held in two six-acre lagoons where solids settle out. The only effluent is of drinking water quality, except for a higher chloride content.

Recurring problems with operation and maintenance of waste treatment facilities at a fertilizer plant led to the construction of an addition to recycle the plant water (386). Significant operation and maintenance savings have been realized, and effluent flow has been reduced by 93-95 percent. Miller (387) reported the development of a plant-scale, continous counter-current ion exchange process capable of producing recycle quality water from the effluent of an ammonium nitrate fertilizer plant. The FMC Corporate Research Center which develops new processes for the manufacture of inorganic chemicals has recently installed a treatment and recycle system to handle the wastewater generated from on-site investigations of prospective chemical processes (389). Wastewater from laboratory sinks, load drains, and kettle and tank washings is treated biologically, filtered and further processed by reverse osmosis. The reverse osmosis product stream is chlorinated and reused.

Quartulli (388) described the process modifications needed to achieve zero process wastewater discharge in an ammonia plant. The approach used involves collection and reusing condensate streams to reduce water consumption. Water is injected into the process as steam, which is reacted with natural gas to generate the hydrogen needed for ammonia production. This scheme is now part of M. W. Kellogg's design for new ammonia facilities and also is in operation at Chevron Chemical, Richmond, California.

IRON AND STEEL

Typical steel plants do not allocate water on the basis of individual processes or recycle water from each process on separate circuits; most do not even record volume or analyze water to individual unit operations (390). Water is usually distributed to clusters of processing units. Higher quality water is infrequently used for lower quality applications in a cascading manner. In some plants, recycling exceeding 98 percent is practiced without significant equipment or product quality problems. Modern equipment is able to accomodate significant impurities with the help of chemical controls. Insufficient information is available on the effect of water quality on product quality. Water recycling and reuse problems are intimately related to steel plant waste recycling and air pollution problems.

The steel industry ranks quite high among those industries requiring large quantities of water per unit of project manufactured (391). Not surprisingly, the industry also produces large volumes of wastewater that must be treated. Much of this wastewater involves rinse waters emanating from the pickling of steel with sulfuric or hydrochloric acid and the rinsing of tin plating operations. Studies at Rohm and Haas Co. have demonstrated that the modified DESAL process may be readily employed for renovating steel pickling and rotating rinse waters. The technique not only solves the pollution problem but also renovates the water for reuse and permits recovery of valuable tin.

In the iron industry recycling of the water insures a definite economy in the consumption of feed water (119). In accordance with the situation and varying structure of different ironworks, production of 1 ton of steel may require the use of 80-200 cubic meters of water (averaging 150 cubic meters)/ton of steel. This requirement may be reduced to 2.5 - 4.5 cubic meters makeup water/ton of steel produced with the use of closed circuits. In the iron industry, recycling may reach as much as 98.5 percent.

Because of the large volume of water used, it has been customary for a steel mill to employ a wastewater treatment system which provides for the reuse of the wastewater (392). These workers described a wastewater treatment system used in steel mills in Japan. The highly recommended process consists of natural sedimentation and high speed filtering.

Hofstein and Kohlmann (393) provided results of an engineering study of five integrated U. S. steel plants to determine how each might ultimately achieve total recycle of water. The plants represent a broad cross section of plant-specific factors (e.g., size, age, location, and available space) that are present in U. S. steel plants. Conceptual engineering designs were prepared for each plant to advance from its present water discharge situation to achievement of the 1984 BAT limitations of the Clean Water Act and finally to achieve total water recycle. Potential treatment technologies for meeting these goals were evaluated; the most promising were incorporated into the plant designs. Capital and operating costs and energy requirements were estimated, and problems associated with implementation of the designs were addressed. Problems include: the lack of steel plant experience with the technologies required, the high cost and energy requirements, the additional solid waste disposal problems, and the more difficult management requirements for sophisticated water systems.

The general concept of water use in the steel industry is that water should pass through a number of systems in series, with blowdown of one system becoming the water supply of the following system (394). Therefore, an industrial water complex consists of individual systems in series and parallel to provide for water circulation and reuse.

The Kaiser Steel Plant at Fontana, California, was forced to recirculate water as a conservation measure and to treat the used water to maintain the quality necessary for succeeding production steps (394). After the plant had designed for this procedure, it become apparent that a situation was created where a water pollution problem could be solved with minimum expenditures. Wight noted that problems of operating an integrated steel plant with a limited amount of water based on the treatment and reuse of the wastewater were many and continuing.

Leidner and Nebolsine (395) presented a review of the cost of steel industry production, the water required, and the resultant wastewater treatment. Generally, water consumption in the modern steel mill varies from 35,000-45,000 gallons per ingot produced. The type of process needed for production determines the amount of recirculation that can be performed which in turn causes variations in the amount of water needed and wastewater produced. Waste treatment is complicated by the fact that integrated steel mills generally produce seven different types of wastewaters that all require different types of treatment.

Water reuse in the steel industry was discussed by Caswell (21). There are two basic methods by which recirculation systems are designed and operated with the choice usually dependent upon the water use system prior to design of the recirculating system. Recirculation can be incorporated on each separate process, or all process waters can be combined, treated to the extent necessary, and used as intake water for all processes. The Kaiser Steel Plant at Fontana, California, utilizes the first system which was in the original plant design. Most systems designed to be added at other plants utilize the second approach. Less extensive treatment is required in the former system, since water of the lowest quality can be reused where it can be tolerated with a minimum amount of pumping, reserving more extensive treatment for the uses requiring higher quality.

Water requirements for various steel-making and processing operations were discussed by Bowman and Houston (396). In particular, the authors discussed water reuse and requirements for chemical and physical treatment required to meet the demands of modern steel mills. Heynike and Von Reiche (397) described several reuse schemes employed to minimize water usage in the steel industry of South Africa including recycle of blowdown of one process as makeup water for another.

Ferruginous wastes, separation techniques, and recycling practices of the steel industry were described by West (398). Sources, quantities, and capture techniques used by the British Steel Corporation were identified. Major problem areas with regard to the recycling effort were discussed.

Nebolsine (399) has reported on steel plant wastewater treatment and reuse. Several different types of steel plant wastewater were considered. These were compared on the basis of characteristics, treatment methods and costs of treatment. Possible economics were considered.

Recirculation of reclaimed water appears to be the trend throughout the steel industry (400). The Armco Steel plant at Ashland, Kentucky, completely eliminated discharge of wastewater to the Ohio River when a hot strip mill water clarification plant was opened. The Ashland plant treatment process is the same as for the Armco plant at Middletown, Ohio.

Hellot (401) reported on pollution control measure in the French iron and steel industry. He estimated that an allocation of 1-2 percent of the total cost of a new iron and steel plant for pollution control would permit recycling of up to 97 percent of the plant's water requirement.

Heynike (402) reviewed improvements in iron and steel industry treatment facilities for waste removal and water reuse. Water treatment for reuse in steel processing in South Africa is based on the counter-current rinse system or cascade system in conjunction with acid regeneration. The vacuum cooling-crystallization process for acid recovery is preferred.

Erasmus (403) emphasized the need for superior quality water for specific applications in a steel mill, and that the most effective use is based on the cascading and in-plant circulating systems. Recirculation systems are prerequistes for optimum water utilization; however, such practice often leads to the same weight of pollution in smaller discharges which could result in unacceptable quality effluents and discourage intensive reuse of water.

Bruehe (404) considered effluent confinement as an ultimate solution to industrial waste problems. Descriptions were given of inplant changes and effluent recycling including pickling acid recovery and treatment of oil-contaminated rolling mill effluents.

Economics in water use in the steel industry have been suggested by Delaine (405) and Howard and Evans (406). These include carefully defining water quality needs for given operations and using wastewater from one process as feed water for another. Correct segregation and treatment of effluents could lead to a closed circuit water use system.

Simon (407) described a maximum circulation of open and closed water circuits which recirculate water for blast furnaces, steel works, and rolling mills. From 1975 to 1978, total water consumption of this plant was reduced to approximately 720 gal/ton of crude steel. The effluent rate was 380 gal/ton of crude steel. Simon reported that further reductions of the total water consumption rate were being investigated.

Jablin and Chanko (408) described details of process and construction, pilot testing, and economics of a new process for total treatment of coke plant waste liquor at an integrated steel plant. The process was expected to provide an economical and technically feasible method for solving a very difficult problem common to the steel industry. The effluent was expected to be suitable for discharge to any stream or use as makeup in a cooling tower or as boiler feed. By-products would be recycled.

Stoner (409) described waste treatment facilities for the Jones and Laughlin Steel Corporation plant at Hennepin, Illinois. Water from filter backwash, softener regeneration, boiler blowdown, rolling solutions, condensate, and other uses are collected for treatment. Special procedures for treating oils, rolling solutions, solids, and sludge are described. The treated water was good enough for reuse. Waste pickle liquor is treated separately and its residues injected into deep wells. Excellent results on a consistent basis have been produced at this plant, but technological changes and proposed effluent standards pose the threat of obsolescence.

The Appleby-Frodingham works of the British Steel Corporation uses recycling systems for all major water demands (410, 411). Although the output of steel has continually increased, changes in the steelmaking process and careful consideration of all aspects of water conservation and pollution prevention has resulted in savings in water usage at the plant.

Extensive reuse of water in a hot rolling mill has been described by Berkbile (412) and consists of sedimentation, filtration, and cooling prior to reuse for scale removal and roll cooling. Some blowdown from the system is used in the cold rolling mill.

A 100,000 gallon per minute water treatment plant at the Armco Steel Corporation, Middletown, Ohio, Works has been employed to permit recycling of the water from hot rolling mills (413). Treatment consists of dosing ferric sulfate and lime in flash mix tanks. Addition of coagulant aids in the flocculation tanks is followed by clarification.

Baker and Pettit (414) detailed reuse and recirculation of water in the steel industry, particularly at the Middletown, Ohio, Armco Steel Works. The treatment process consists of sedimentation, coagulation, flocculation, and clarification. Features of the system include flexibility, ease of maintenance, provision of variable flow and raw water quality, minimum operating manpower, maximum water conservation, and maximum degree of pollution abatement.

Thompson (415) described 17 separate recirculating and waste treatment systems installed at the Armco Middletown Works. Actual water utilization was reduced to 5 percent of that required for once through water use.

Treated wastewater at the Chrysler Corporation foundry at Indianpolis, Indiana, is reused in the gas quenching system with plans for recycling to the external cupola cooling system (416).

A recycling system was installed both on the blast furnace and the sinter plant of the Interlake Steel Corporation (417). These systems consisted of polyelectrolyte addition, sedimentation, and sludge concentration, as well as cooling towers. The recycle systems were phased into operation at both plants with no downtime. The ultimate goal was for the complete plant to achieve closed-cycle operation. Krikau and De Caigny (418) described problems associated with water recycling units installed at Interlake Steel. Scaling and lime precipitation were among the difficulties reported.

In order to solve the waste disposal problem created by the pickling of iron, a regeneration plant was designed at the Hilton Works of the Steel Company of Canada (419). In the process, the acid content of the pickle liquor is recycled for further use and iron oxide is produced as a by-product. Iron oxide produced is 97 percent pure and can be converted into iron powder by a number of methods. The production of iron could be quite profitable. The regeneration plant is basically a simple process, but due to production changes or breakdowns, running the unit can be critical.

The National Steel plant at Weirton, West Virginia, replaced the old mill rolls coolant system of water and oil directly applied to the rolls with a recirculating system with vacuum filters (420). Only 50,000 gpd of river water is used with the new system compared to 30 mgd with the old system. Fluid losses occur only through evaporation and leakage.

Studies for a total wastewater control program at a large, integrated steel mill were begun early in 1975 (421). The study and design work on this project has shown that many possibilities exist in steel mills for recycle and reuse of water. Large quantities are required for flume flushing, a use which does not require high quality water. Filtration of hot rolling mill wastewaters produces a water quality idealy suited for recycle. In some cases, some limited treatment followed by recycle is more practical than treating wastewaters to an extensive degree for discharge, although operational difficulties may occur. Careful review of both water quality and operational requirements for each process is necessary before recycle and reuse should be considered. However, recycled water after modest treatment sometimes is of better quality than a surface water source after a period of rainfall. It may be found that the plant is already using very poor-quality service water on many occasions, and that reuse may even reduce the variability in the service water supplied.

The fully integrated iron and steel works of the Japan Steel and Tube Corporation at Fukuyama began producing steel in August, 1966, with strip steel as the primary product (422). A horizontal pickling line using HCl and regenerating the spent acid in roasters was installed. Operation of the pickle line and regeneration plant were reported as satisfactory. The pickling and regeneration facility presented a tangible contribution to efforts of the steel industry throughout the world toward constantly raising the quality of steel products while reducing the pollution of the water resources they must rely upon.

The water pollution control facility at DOFASCO in Hamilton, Ontario, Canada treats rolling mill water from the mill scale pits and primary settling basins (423). A splitter box distributes mill water to seven of the eight cells in each of two ultra-high rate, dual media anthracite filters. Some of the filtered water is recycled to the acid generation plant and the hot mill, while the rest is discharged to a sewage system.

The United States Steel South Works in Chicago, Illinois initiated a three-step program to improve the quality of water discharged (424). The first phase of the project was to provide treatment for the south side blast furnace group. The second phase provided a recycle system for the gas washer water from the north side blast furnace group, as well as a central treatment plant for primary treatment of all process water. A cooling tower unit was installed to chill clarified effluent from the thickners before recycling to the furnaces. Wet, high-energy, gas cleaning plants equipped with water recycling systems, were installed to treat process water. In the third phase of the program, a recycle system was installed for gas washer water at the south side blast furnace group. Complete recycling of all plant process water was provided in the fourth phase of the program.

Zero discharge has been achieved at a steel mill by a treatment train of sedimentation, skimming, chlorination, filtration, and cooling (425). Renovated water is completely reused in the plant.

Theegarten and Von Hartman (426) described the use of a recycle system in operation at a West German hot strip mill. The company selected to implement a recirculation system due to the high cost of raw water, the need to meet stringent discharge requirements, and a high effluent discharge surcharge. Important criteria of design and operation were discussed.

Nauratil (427) discussed a recirculating water system for a Czechoslovakian steel mill. Mizuno (428) stated that over 90 percent of the water used in many Japanese steel mills was recirculating water. The high level of recycle was made possible by improved suspended solids removal techniques. Katsumi and Nagasawa (429) reviewed the development of water reuse practices for the steel industry in Japan.

Harrison (430) described the recirculating use of blast furnace gas washwater at the Bilston (England) Works. The recirculation system included treatment of blowdown steam by alkaline chlorination for cyanide, precipitation of heavy metals, and sedimentation. Another recirculation system reported for blast furnace gas wash water employed treatment of the water by settling before reuse (431). Shah (90) reported that additional treatment of blast furnace flue dust wash water and rolling mill effluents is normally required before these effluents can be recirculated.

Kemmetmueller (432) described a process for dry quenching of coke, thereby avoiding generation of quench washwaters normally associated with coking. The process is required of all new coke plants in the USSR. Among the advantages claimed is that there is no air or water pollution because dry quenching is carried out in a completely closed operation.

Sukhomlinov and Vinarski (433) discussed recycling biologically treated coke by-product wastewaters. Corrosion, scaling, biological fouling, and air pollution were all reduced as a result of recycling.

Martin (434) discussed water use and reuse potential for blast furnace operations, steelmaking, continous casting, hot rolling, cold rolling, and pickling. For each area general water quality requirements and waste treatment techniques were summarized.

Recycle of wastewater from rolling mills has been reported following chemical coagulation and sedimentation (430), sedimentation, sand filtration, and temperature reduction (435). Hammon (436) reported on a system of gravity separation, flocculation, sedimentation, oil skimming, sand filtration, and evaporative cooling to treat 4.4 million cubic meters of recycle process water at a West German rolling mill.

Barker et al. (437) and Smith (438) described investigations on a pilot-plant treatment facility which served as the basis for mill-scale wastewater treatment and reuse in the steel industry. The treatment system involved sedimentation to remove heavy mill scale, oil, and grease followed by chemical coagulation, flocculation and clarification. Clarified water was used for cooling purposes and for pressure demands to satisfy mill requirements.

Coleman (439) reported that waste lime from acetylene manufacture could be used to treat pickle liquor. Neutralized wastewater was pumped to a battery of sedimentation lagoons. Renovated water could be reused in the plant.

Kruezer (440) discussed water needs and wastewater aspects of continuous casting. A two-system recirculating water facility was described. System I treated and reused water that had come into direct contact with steel. Treatment consisted of scale and oil removal followed by a cooling tower. System II handled non-contact cooling water in a closed cycle through a cooling tower and chemical treatment facility. Blowdown from System II was used as makeup for System I.

Tockman et al. (441) provided results of a literature survey of current western European and Japanese water pollution control technology in the iron and steel industry. Recycle technology was identified as being practiced to a high degree by the Japanese. A variable recycle rate was found to be practiced at British and western European steel plants. Summaries of typical pollution control operations are described and comparative date are provided.

Touzalin (442) described an installation to treat, clarify, cool, and recirculate blast furnace and sinter plant wet scrubber effluents in one unified system. Hellot (443) discussed current efforts in biological and physical-chemical treatment of iron and steel production wastewaters for reuse.

Jablin (444) reviewed the pollution control timetable for the Alan Wood iron and steel plant and described processes installed to date. Treated wastewater is recycled following oil removal, acid neutralization, clarification, and sludge lagooning. Mace (116) described recycling operations at the Armco Steel Corporation plant in Houston, Texas.

Brough and Voges (445) described the use and reuse of water in a basic oxygen furnace for the following operations: hood cooling, oxygen lance cooling, spark box spray cooling, gas scrubbing, and gas after-cooling. Duval (446) patented a process for recovering the zinc content of flue dust using spent pickle liquor.

The desalting recovery facility for wastewater from a cold rolling mill of the Kobe Steel Manufacturing Company Limited was described by Kotegawa and Maekawa (447). The wastewater was pretreated by neutralization, colloidal separation, precipitation separation, and filtration. In the desalting facility, the waste was first treated with aluminum hydroxide in a high pressure filter to remove oil components, and then in a cation exchange tower, a decarbonation tower, and finally in an anion exchange tower. Treated water was mixed with plant water which by-passed the desalting facility and city supplied water and reused by the factory. About 89 percent of the wastewater generated at the mill can be reused.

An overview of waste treatment practices in the steel making industry was given by Koehrsen and Krikau (448). A review of various types of reuse schemes that are commonly employed in the industry was provided.

Regeneration of wastewaters from steel works and rolling mills for recirculation was reported by Albrecht (449). The wastewater is passed through a sedimentation basin and then a hydroclone. Finally, the addition of a flocculating agent, followed by a two-step gravel filter, removes solids of micron size.

Miller (450) reported that water can be pumped through self-cleaning strainers and then reused in steel mills. This practice will reduce the suspended solids load to the receiving stream by as much as 94 percent.

One of the most pressing problems in the steel industry is disposal of mill scale effluents (451). This is the liquid/solid waste created when steel is washed clean of oxidized scale. One southwestern rolling mill has solved this problems by recycling 4,000 gpm of scale pit effluent after dual-media filtration. Filtered water is collected and held in a 500,000 gallon reservoir for service in roll cooling, descaling, washdown, and cleanup areas.

De Yarmen (452) investigated specific systems for renovating the water employed in wet flue gas scrubbers for recycle and reuse. To reduce the level of pollutant discharges in wastewater resulting from wet scrubbing of blast furnace flue gases, a portion of the clarifier overflow is recycled (453). Recycle gas-cleaning systems can be operated similarly to once-through systems, but the quality of the recycle water must be monitored to maintain calcium carbonate equilibrium.

Studies of an electro-membrane process for regenerating acid from spent sulfuric acid pickle liquor have indicated that the process is technically feasible (454). Estimated treatment costs were given.

Fenner and Higgins (455) and Higgins (456) discussed use of ion exchange resins for the recycle of spent pickle liquor components. Robert (457) reported that gelatinous silicon could be removed from spent H_2SO_4 liquor by filtering through bags made from synthetic fibers. The filtrate was further treated to remove $FeSO_4.7H_2O$ to recycle the acidic liquor. Lefevre (458) described an ion exchange method employing strong cationic exchangers to recover iron and recycle HCL to the pickle line.

A process has been developed by Pori, Incorporated, for the regeneration of hydrochloric acid from spent steel mill pickling solutions (459). A sequence of several unit operations is involved in the Pori process. Equipment consists of an evaporator oxidizer, hydrolyzer, falling film condenser adsorber system, tail gas scrubber, moving bed filter, and necessary pumps, storage tanks, and utilities. A regeneration plant was to be built at J and L Steel Corporation, Cleveland, Ohio. This low temperature process will produce high strength acid and will eliminate the need to install heat exchanges in pickle lines and to control concentrations of the components in spent pickle liquor. In addition, soluable or usable products such as FEC 13 and FE 203 will be produced.

Effects of oxygen converter operation methods on the dissolved solids content of gas scrubbing water, and the suitability of the water for recycle were discussed by Pantelyat and Kuznetsov (460). Available processes for recovery of spent pickling liquors were reviewed by Hitzemann (461, 462).

The magnidisc water treatment process is especially suited to the treatment of effluents from steel works (463). The treatment process is based on the magnetic separation of solid particles from polluted water. The magnidisc system has satisfactorily treated the effluent from the Storfors Steelworks, Sweden. The cleaned water at Storfors is recycled. The magnadisc system is very compact; the moving parts are few and slow-moving; and some dewatering of the sludge occurs as it moves through the discs.

A patent has been issued for a process whereby flushing liquor from a gas main of a cloke oven undergoes separation in a tank to obtain water which is essentially free of tar and solids and to obtain tar which is essentially free from water and solids (464).

Dembeck (465) cautioned that circumstances change from plant to plant and that it was impossible to take treatment methods from one location and use them at another without intensive preliminary investigations.

METAL PLATING AND FINISHING

Friedberg (466) reported on closed-loop recovery and recycling of metal finishing wastes for industrial systems, citing case histories of waste treatment requirements and their solutions with closed-loop systems.

Leon and Leon (467) reported that water consumption was reduced by 90 percent and waste heat reduced substantially for a metal finishing plant by installing a reuse and recycle system. Rinse waters were recycled and cooling water and steam condensate reused. Nickel containing rinse water was passed through an ion exchange column, then mixed with other rinse waters. treated with spent acid bath solution, and then lime.

Missel (468) suggested that many spent plating solutions could be reused. He also suggested use of multiple-tank, countercurrent rinsing of plated parts to reduce the volume of wastewater to be processed.

Countercurrent rinsing, use of sprays rather than baths, segregation of different types of plating baths, and treatment by ion exchange, activated carbon and reverse osmosis make possible 90 percent water reuse in the metal finishing industry (469).

Trnka and Novotny (470) described the feasibility of a rinse and recovery system that can be installed in almost any metal finishing line and does not harm the environment because no plating solution exits to the sewer. The zero discharge system is an innovative system for use in the metal finishing industry. A conventional multistage aqueous rinsing system is replaced by a two-stage solvent spray rinse followed by a single-stage aqueous immersion rinse. By continously purifying and recycling the baths, appreciable savings in operating chemical costs can be realized.

Von Ammon (471) discussed advantages and problems of ion exchange and recirculation from the experiences of three metal finishing plants in Germany. The type and situation of the plants, collection of rinse waters, design and operation of the ion exchange process, properties of the circulated water, wastewater treatment properties of the final effluent, and economic considerations were discussed. Recirculation was found to be more economical unless costs for water supply are extremely low or no waste treatment is required. Recirculation results in reduction in waste quantity which gives obvious advantages for reduced waste treatment and a lower pollution load on receiving waters.

Marino (472) discussed the technical and economic feasibility of closed loop systems in the electroplating industry to attain zero discharge of pollutants by 1983. Capital costs were summarized and reasons for their increase was discussed. A wastewater treatment and reuse system was described. According to Barrett (473), development of an effluent treatment and recycling system is part of the manufacturing process.

A discussion of the advantages of using resource recovery equipment has been presented (474). A survey indicated that recovery practices have enabled electroplating companies to conserve chemicals and reduce the cost of chemical treatment for meeting discharge limits for heavy metals. A breakdown of recovery costs from several plants and several types of recovery equipment in the plants was presented.

Burkhart (475) proposed several design schemes for recovering water and useful materials from electroplating processes. Purpose of the designs was to improve water balance of the process cycle and to avoid contamination by effluent discharges. Kreszkowski and Jackson (476) discussed effluent standards for electroplating plants in the United States and proposed possible modifications for water reuse.

Pinner (477) discussed recovery of water and valuable materials in the electroplating industry in the United Kingdom. The integrated treatment of eliminating toxic wastes and recovering valuable materials have become more feasible with discovery of new closed loop systems. For example, after a process containing toxic or valuable recoverable materials, replacing the water rinse with a recycled chemical rinse permits the metals to be precipitated out and the clear liquid to be returned as a secondary rinse. Pinner pointed out three techniques for extracting metals from rinse water: chemical precipitation, electrolytic recovery, and ion exchange. If metals are not extracted, they can be concentrated by evaporation and reverse osmosis to levels suitable for returning to the plating tanks.

Satee (478, 479) discussed the treatment and disposal of anodizing effluents. He stated that the ideal method of treating water in an anodizing plant is for reuse within the plant.

Lancy and Rice (480) discussed commonly used waste treatment systems for upgrading metal finishing facilities to reduce pollution. Savings achieved in water reuse opportunities and from chemical and metal recovery steps built into the waste treatment scheme may allow economics to offset treatment cost, thereby reducing overall operating costs.

Domey and Stiefel (481) reported on the development of a waste treatment scheme for metal finishing operations in Massachusetts. Counterflow rinsing techniques as well as the application of water reuse were instituted. Waste flows were reduced by as much as 90 percent. Consequently, it was possible to design small batch-type treatment systems for these and other similiar firms lacking both available space and capital for pollution abatement facilities.

Almag Chemical Corporation, Baltimore, Maryland, a metal plating and finishing specialist plant, has developed a closed-loop system for wastewater decontamination (482). The system continuously decontaminants wash and rinse water, and the clean water recirculates through the process. No wastewater is discharged and no fresh water is introduced. Water costs have been reduced by about 75 percent. Individual systems had to be divided for each plant area or process because of the diversity of operations in the plant. Operating costs are offset by the savings in water costs.

Swalheim and McNutt (483) described recovery and recycling of electroplating plant effluents as extremely desirable and described some practical and economical methods to avoid pollution problems. Kreszkowski and Tuznik (484) reviewed recycling and recovery of materials in the electroplating industry.

A Chicago plating operation featuring recirculation of metallic rinses has been described (485). The operation includes in addition to the recirculation feature, acid, alkali, cleaner dumping and batch treatment, preliminary sludge collection, final pH adjustment, and final sludge collection, drying, and thickening. There are recirculating rinses for zinc, nickel, chromium, and copper.

The use of countercurrent double rinse tanks that require water addition only when the reuse water is too dirty, can reduce drainage system requirements in the metal finishing industry (23). Nohse (486) attempted reuse by a cascade rinse procedure during metal finishing operations and found that it was not always successful. An integrated recovery method was reported to be an efficient means of maintaining strict control of metal finishing solutions and maximizing the recovery of recycle water and other valuable materials (487).

Kolzow (488) discussed water renovation and reuse in the metal finishing industry. He detailed a chromium and zinc recovery system that was installed to reclaim the wastewater so that it could be totally reused. Treatment of a metal finishing waste also was discussed by Snowden (489). The renovation system consisted of cyanide treatment by alkaline chlorination, nickel removal by precipitation, and chromium and copper treatment by reduction and precipitation. Because of the high quality of the effluent, treated wastewater was returned to processes in the plant.

Installation of a 25 gph "waste saver" evaporative recovery system has enabled the Dzus Fastener Company, West Island, N.Y. to develop a closed-loop cadmium plating cycle. The company barrel plates its steel products with cadmium (490). The evaporative recovery unit receives rinse water from the first of three counter-flow rinse stages through an intermediate reservoir. It then evaporates the rinse water and returns distilled water directly to the rinse tanks. The concentrate is returned to the plating bath. Use of this system has eliminated chemical consumption from the previously used chemical-destruct system; eliminated losses of plating chemicals in the drag-out; reduced water consumption; and, substantially lowered costs for sludge removal. Through savings, the system was expected to pay for itself within two to three years.

Pengidore (491) described results of use of counter-current rinsing on a high-speed tin plating line. Performance of the rinse system and recovery of chemicals in the concentrated rinse effluent were discussed. The report also included a description of problems encountered with water recycling and new technology and methods for solving these problems. Fischer (492) described a practical example of rinse water recirculation in combination with the Lancy integrated effluent treatment method.

A complete wastewater treatment system has been installed as part of a new S.K. Williams Company job plating facility (493). Most of the metal finishing processes common to the industry are included in the plant. Despite the wide range of toxic materials used in these processes, the treatment system has provided an effluent essentially meeting U.S. P.H.S. drinking water standards. Operating experiences are described, and data are presented on operating and capital costs for the entire system.

McDonough and Steward (494) described the waste treatment installation at a contract metal finishing plant of the S.K. Williams Company. Integrated systems are used to intercept specific wastes before they enter the rinse waters. With the use of the integrated treatment system, rinse waters do not become contaminated; and the effluent is suitable for reuse. An additional benefit of the system is that it eliminates the need for equipment to handle large volumes of effluents.

Collison (495) described an integrated treatment scheme with rinse-water recirculation in a metals plating facility. Rinse-water requirements were reduced approximately 85 percent.

McGarvey and Fisher (496) reported that a water recycling process could be installed and operated at a zinc bonderizing plant at one-half the cost of a conventional non-recycling system. Closed loop recycling was reviewed by Webster and Olson (497) and Swartz (498) as a means of meeting zero discharge standards in the aluminum and aluminum products industries.

Kneysa (499) described a fixed-bed electrolysis process for purification of electroplating wastewaters, recovery of valuable materials, and recycling of wash water. The process was applied to treatment of copper containing electroplating wash waters.

Although other techniques are under development, evaporation, reverse osmosis, and ion exchange are the most commonly used processes for rinsewater recovery (500). Each of these techniques has particular advantages and disadvantages, and the best technique or combination of techniques will depend on factors specific to each application.

Treatment of wastes from the metal finishing industry was explored by Cheremisinoff et al. (501). Chromium, cyanide and other rinse waters have been treated by single and multiple stage evaporation. This process is economical only for concentrated rinses and requires segregation of wastes by compatible types, the use of various means for excluding or removing impurities, and careful rinsing and water use by the metal finisher. Evaporated water is returned to the rinsing system.

One of the recent developments in recycling, an evaporative atmospheric recovery system, has been reviewed by Kolesar (502). A typical chrome closed-loop evaporative atmospheric recovery system is described. Cost of the system for a plating plant depends on individual installation and the type of plating involved. Comparative operating costs of plating rinse treatment at a plant of an automotive parts supplier is quoted, showing definite economic gains without affecting process efficiency.

Barta (503) discussed automatic recovery of plating wastes. The Pfaudler automatic closed-loop evaporation plant for treatment of plating wastewater and recovery of cyanides was described and illustrated. Rinse waters were drawn into the evaporator by vacuum and circulated between the reboiler and the separator until they were concentrated sufficiently for return to the plating baths. The distillate was used as makeup water for the rinse tanks. Operating costs were less for those in chemical treatment.

Elicker and Lacey (504, 505) reported on a six-month study of chrome plating operations. This EPA demonstration project documents the practicality of a new evaporative approach for recovering chromic acid from metal finishing rinse wastewaters, as well as the economics of the system under actual operating conditions. Design of the system centered around a climbing film evaporative recovery unit, a cation exchange column, and monitoring equipment. Results of the study showed that the system can be accommodated with little impact on the existing operation. The recovered chromic acid can be recycled back into the bath without affecting product quality. The recovery system can decrease chromic acid consumption significantly and is economically viable.

Evaporative recovery of plating wastes has advanced from manually operated batches to completely automated, continuous systems incorporating processes for removal of impurities and recovery of water (506). Applications include a wide variety of plating and treatment baths. By reusing the distallate for rinsing purposes, plating has become a closed-loop process with no waste effluent. Over the years, problems have arisen which have led to innovative changes in the overall system. Separate rinse tanks are employed in each line.

The Rockford Linen Products Company employs an automatic evaporation system for concentration of plating rinse waters to permit reuse (507). Economics of the process were considered, the automatic operation described, and flow diagrams presented.

Imai (508) reviewed different recycle methods which could be used to reduce electroplating effluent discharges. Obrizut (509) discussed the use of a climbing film evaporator which was used to recover chrome and recycle the rinse water. Bhatia and Jump (510) presented the climbing film evaporator as an effective technique for recycling plating materials such as chrome.

Because of the inherent disadvantage of end-of-pipe treatment, loss of valuable plating chemicals, cost of treatment chemicals, and cost of sludge disposal, increasing attention has been focused on closed-loop recovery methods (511). A field test was conducted to demonstrate closed-loop recovery of zinc cyanide rinse water at a job plating facility. Reverse osmosis treatment of rinse water was supplemented by evaporation in order to achieve the volume reduction necessary for return of a concentrate to the plating bath. The permeate from the RO unit was recycled to the first rinse after plating while the distillate from the evaporation was recycled to the second rinse after plating. Continuous, unattended operation of this system was demonstrated with no adverse effects on plating quality.

Economics of the combined RO-evaporation system were assessed for a system designed to provide rinsing equivalent to the present two-stage counter-current rinse at the demonstration site (511). The analysis showed that the total operating cost (including amortization) was somewhat less for the combined RO-evaporation system than for evaporation alone. The minimum cost occurred for 90 percent water recovery in the RO system. However, credits for rinse-water recovery were insufficient to completely off-set the total operating cost of the recovery system.

The New England Plating Company in Worchester, Massachussetts, was the site of a field test to evaluate the use of a reverse osmosis membrane in hollow fine fiber configuration for the closed-loop treatment of rinse water from a Watts-type nickel bath (512). A schematic diagram of the field test system was presented. Rejections observed for nickel, total solids, and conductivity were generally very good. Total annual operating costs were projected.

Reverse osmosis can be used for the closed-loop treatment of plating bath rinse waters with recycle of the plating chemicals and reuse of the purified water in rinsing operations (513). Closed-loop RO for treatment of segregated rinse waters and for treatment of mixed effluents are discussed in detail with reference to the advantages and limitations of each.

Kremen et al. (514) reported that a reverse osmosis process and system had been developed to purify a dilute waste stream from a metal finishing plant. The system achieved a 95 percent water recovery. Plant performance, after shakedown, has been in good agreement with design predictions. Takao (515) described a recycle system based on the use of reverse osmosis.

Bays (516) described a system in which plating bath rinse water was completely recycled with only dry salt and metal oxides as waste products. The semiautomatic RO system recycled up to 56 million gallons per year of wastewater. Advantages of closed-loop recovery of electroplating rinse waters using reverse osmosis have been noted (517). Principle advantages are low capital, energy, labor costs, and small space requirements.

Galomb (518) reported on laboratory studies on the feasibility of reverse osmosis for recovering nickel from rinse waters from nickel plating operations. A process scheme for recovery and direct return of chemicals to the plating bath was proposed. A preliminary cost estimate indicated favorable economics with the added advantage of pollution control.

On the basis of laboratory studies and subsequent plant trials on an industrial plating line, nickel plating rinse waters were effectively treated by reverse osmosis to reclaim reusable materials (519). Cellulose acetate membranes were used to recover greater than 99 percent of nickel valves from the waste rinse streams. In addition to the favorable economic aspects, the "closed loop" reverse osmosis reclamation system can make a significant contribution toward eliminating unnecessary discharge of contaminants and total dissolved solids into the environment.

Reverse osmosis treatment is saving materials and water at the Evanston, Illinois, plating plant of VCA Corporation (520). More than 8,000 square feet of plastic is electroplated daily at the plant. The RO treatment has reduced weekly copper consumption by one-third. In addition to returning concentrated materials to the plating bath, the closed-loop RO system reuses purified rinse waters. The RO unit is an automatic compact unit called an Osmonic Osmo-30043.

Beckman Instruments, Inc. implemented a program at its Porterville, California, facility to lower the reject rate of the plating operation by improving the quality of rinse waters (521, 522). In addition, the program reduced water consumption and complied with EPA discharge requirements. Reverse osmosis was chosen as the principal method for water purification. A solar evaporation pond was selected as the means to deal with wastes which could not be recycled through the RO system. A block diagram of the waste treatment system, including the pretreatment filter system, is shown. The system has reduced water consumption by about 70 percent and lowered the cost of shop rejects to less than a third of its previous value. In addition, it fully complies with the 1983 goal of zero discharge.

Field tests of RO were conducted on copper cyanide rinse waters at two different sites: Whyco Chromium Company and New England Plating Company (523). At both sites, closed-loop treatment was used with plating chemicals recycled to the bath and purified water recycled to the rinsing operation. The objective of the tests was to establish under actual plating conditions, the feasibility of RO treatment for copper cyanide plating wastes. It was concluded that RO can be used to close the loop in copper cyanide plating. However, care must be taken to insure that adequate membrane life can be achieved.

The North State Research and Development Institution, Minneapolis, Minnesota, evaluated 17 different reverse osmosis membranes as to their ability to separate heavy-metal ions, acids, bases, and cyanides from metal finishing wastewaters (524). Although no one membrane was found to be effective for all effluents, membranes of five different polymers showed considerable promise. Preliminary engineering considerations for reverse osmosis applications to treatment and recycle of acidic copper plating bath rinse waters showed a 99.8 percent copper recovery and a 99.9 percent recovery of water.

Antoine (525) described two different solutions for the partial recycling of wastewaters from the pickling rinsing of metallic workpieces prior to galvanization. According to one solution, effluents are neutralized with lime, and then oxidized for conversion of free acid and iron chloride into calcium chloride and ferric hydroxide, the latter being eliminated in a static decanter. The solution obtained is treated continuously with sulfuric acid for conversion of calcium chloride into hydrochloric acid and calcium sulfate, the latter being continuously removed by filtration or decanting. Another solution to the recycling problem, permitting different uses of recycled water, is separation of the total effluent by RO into a clear fraction suitable for direct recycling and another residual fraction.

Donnelly et al. (526) examined reverse osmosis treatment of plating bath rinse waters. Emphasis was placed on closed-loop operation with recycle of purified water for rinsing, and return of plating chemical concentrate to the bath. Three commercially available membranes were evaluated experimentally; tubular, spiral-wound, and hollow-fiber configurations. Tests were conducted with nine different rinse waters prepared by dilution of actual plating baths. Advantages and limitations of two RO processes and specific membranes and configurations were discussed.

Major pollution problems in the automobile industry result from the large quantities of water used in metal finishing and machining (527). Both economic and environmental benefits will result if metals and chemicals can be retrieved and the volume to be disposed can be reduced by the removal of water. One such technology is reverse osmosis. Benefits and limitations of reverse osmosis were discussed.

Koyama et al. (528) conducted laboratory studies on the recovery and reuse of rinse water from tin-nickel plating operations by reverse osmosis and ion-exchange processes. The authors suggested a closed water cycle process of tin-nickel alloy plating which will affect almost complete recovery of chemicals and direct return of the concentrated product into the plating bath.

The function and uses of ion exchange, reverse osmosis, and ultrafiltration in the purification of wastewaters generated in the sheet-metal processing industry in general, and in electroplating shops in particular, were described by Marquardt (529).

More stringent effluent restrictions forced the General Electric range products plant in Cicero, Illinois, to develop an effective economical method of treating 45,000 gallons of wastewater produced daily from the chrome plating line (530). The two-bed system selected is described. Wastewater first passes through a column containing Amberlite IR-120 exchange resin where iron, nickel, trivalent chromium, and other cations are removed. The second unit containing Amberlite IRA-402 exchange resin removes hexavalent chromium, fluorides, sulfates, chlorides, and miscellaneous anions. The resins are automatically regenerated.

In 1972, Oldsmobile installed two ion exchange systems at its facility in Lansing, Michigan, to treat nickel rinse water from the bumper plating lines (531). The treatment systems were designed to accomplish three purposes: 1) reduction of nickel metal in the plant effluent discharge to the city of Lansing; 2) recovery of nickel metal; and 3) recovery of the rinse water itself. Although the ion exchange processes did not fully achieve all the objectives hoped for, it still recycles a combined 50 million gallons of water and recovers about 30,000 pounds of nickel annually. In addition, significant reductions of nickel metal in the plant effluent have been observed.

A pilot plant study was carried out which demonstrated the effectiveness and economic feasibility of a unique ion exchange process referred to as "acid retardation" for purifying spent phosphoric acid used in bright finishing aluminum parts. The anion resin retards phosphoric acid as the processing solution flows through the bed (532). Aluminum remains in the waste solution and passes out of the column in the effluent. Acid is eluted from the bed with water, eliminating use of chemicals which are needed to regenerate resin in conventional ion exchange systems.

A method and apparatus for handling chromium containing anions from the rinse bath which is used to rinse plated objects has been invented (533). Purified rinse water from the plating operation, after having passed through ion-exchange resin, is used for rinsing of plated objects, backwashing and rinsing of ion-exchange resins, and makeup of ion-exchange resin regenerant solution. The solution of chromium-containing anions is delivered to an anion-exchange resin where chromium-containing anions are removed and exchanged for hydroxide ions thereby forming purified water.

A treatment system developed for use with liquid waste generated from surface coating processes has been designed so that no effluents will be created, and all liquids will be circulated within a closed system (534). All liquid wastes that enter the scrub water tank are then sent to the ion exchange resin treatment unit where liquids are classified into groups and treated separately. Deionized liquid circulates back to the scrub water tank. Recovered, newly created waste from the surface coating process and other miscellaneous liquid waste are sent together to the chemical treatment system where liquids and solids are separated. Separated liquid is concentrated and evaporated. Condensed water is circulated back to the scrub water tank. Solids are mixed with solid sludge from the separation processes. Metals in the sludge are recovered by contracted metal refiners and reused. Problems in the system include material corrosion and noise.

Petzold (535) introduced a recycling and automatic operations method that was designed for recovering metallic salt from electroplating rinse baths. Metal salts could be separated by ion exchange and recovered in concentrations ranging from 150-225 grams per liter. It was determined that at these concentrations the treated rinse solution would be suitable for direct use in the plating bath.

The technological and economic advantages of use of ion-exchange resins for wastewater treatment in the extroplating industry have been described. Water treated by ion exchange is of constant quality regardless of fluctuations in ion concentration. Ion-exchange resins are also suitable for the recycling of process water after the removal of ions, and for the recovery of precious metals from liquids (536). It is possible to economically remove copper, nickel, zinc, cadmium, sodium, chromic acid, cyanides, phosphoric acid, and nitric acid from process waters provided their individual concentrations are below 500 mg/liter.

Peterson (537) proposed a closed-loop system for treatment of waste pickle liquor. The system consists of a crystallizer, ion exchange unit, oxidizer, and hydrolyzer. All acids are recycled.

Silman (538) noted that equipment is very sophisticated and requires special skills, resins are expensive and can be ruined beyond regeneration, and temperature of rinse baths must be carefully controlled because of heat conservation where the recycle of rinse water is practiced.

Peyron (539) discussed recirculation and direct treatment of electroplating wastewaters. The description of an ion-exchange effluent treatment plant was included.

Ayusawa et al. (540) were awarded a patent for an ion exchange process for treating zinc electroplating solutions. The process removed iron and lead impurities and allowed recycle of the waste zinc solution. A patent has been issued for a process in which chromate ions are removed and recovered from feed by passing the water through a bed of basic anion exchange resin (541). An alkaline solution containing regenerant ions is then passed through the bed to recover chromate ions.

The bronze plating facility of Dowty Mining treats and recycles rinse water affected from plating operations using a cyanide treatment system and a neutral treatment system (542). In addition to recycling treatment plant effluents, Dowty recycles its second stage rinse water without treatment. The recirculation of 90 percent of rinse water has resulted in a substantial annual savings on fresh water costs.

Zimmer (543) described an economic water recovery system for metal plating facilities which combined direct filtration and ion exchange. Various methods of treatment of rinse water from electro-chemical processes including chemical treatment, controlled recirculation, ion-exchange, electrolytic processes and integrated effluent treatment were presented by Silman (538). He reported that 50 - 80 percent savings of water requirements could be realized by the controlled recirculation method.

A patent has been issued for an invention involving a method and apparatus for neutralizing etching agents, and separating metallic and fibrous particles and particulate matter from a fluid solution to reduce the particulate level in the solution and condition it to permit its reuse in the manufacturing process and its ultimate disposal without adverse affects to the environment (544). The process is based on placing a plastic material carrying an electrostatic charge (electret) in contact with the fluid solution.

A closed-loop water recycling system was used by the Eaton Corporation to solve wastewater discharge problems from metal cleaning processes (545). The process consisted of a first stage in which wastewater discharge is mixed in an equalization pump. The second stage finds the waste pumped into the neutralization system. Waste is discharged into a transfer tank and then to a clarifier. Clarified overflow is transferred to a clear well, and the clear water is pumped through a polishing filter and then back to the wire coil rinsing tanks.

Brackett (546) described a process by which wastewater from metal plating and metal etching operations is treated for recovery of useful solid contents while permitting recycling of water through the plants without creating sludge deposits that result from ordinary wastewater treatment methods. The method does not require addition of sludge-forming chemicals to the water; saves the cost of valuable materials reclaimed from the wastewaters; and does not require large, expensive evaporator or freeze units. The process consists of equalization tanks, pH adjustment facilities, filters, reverse osmosis or electrodialysis units, organic material removal unit, evaporator, freeze crystallizer unit, and centrifuge.

A patent has been granted for a method of purifying a galvanizing and/or metal cleaning plant pickle liquor to permit reuse (547). The operation includes placing a cathode and an anode in the liquor and passing a DC current through the liquid. Metal molecules are recovered by means of a magnet located near the cathode. Iron oxides and other insoluble salts are formed near the anode and can subsequently be removed by filtration.

The Atomics International Metal-Cyanide Removal Process for plating rinse waters was evaluated in pilot-scale studies by Chen et al. (548). The process uses an electrolytic cell with a tin particle-bed cathode, a graphite particle-bed anode, and a cellophane separator in which relatively low voltage is used to remove contaminants from metals processing wastewater. Cost estimates for the process based on the pilot-plant unit design were projected.

A treatment system for reuse of wastewater in the electronics metal finishing industry was described by Miller (549). Wastewater passes through a disc filter for removal of large solids and a high rate anthracite coal filter for removal of fine solids. After separation of oil and water at pH 2.5-3.0, a weak ion-exchange resin is used for neutralization. Treated water is used as feed for a demineralizer system or as makeup for a cooling tower.

Full-scale demonstration of electrodialysis for closed-loop treatment of brass plating cyanide rinse waters was conducted in the Keystone Lamp Manufacturing plant at Slatington, Pennsylvania (550). In treatment of actual rinse water the system was only 25 percent as effective as anticipated. Numerous attempts to improve the efficiency of the installation were unsuccessful, and the works were terminated. In this study, the electrodialysis system was tested on sodium copper cyanide solutions, whereas the actual rinse waters contained sodium copper zinc cyanide. To avoid future failures, the membranes need to be laboratory tested on actual wastewaters before full-scale demonstration.

A method was developed in a pilot study by Volco Brass and Copper Company which reduces water consumption by 90 percent through chemical rinsing and water reuse (551, 552). The sulfuric acid pickle solution is regenerated and high purity metallic copper recovered through continuous electrolysis. A design for implementing the new process is included.

The development and successful demonstration of laboratory and pilot-scale flouride treatment techniques for selected aerospace and metal working industry chemical processing solutions and rinse waters were described by Staebler (553). Reuse of treated rinse waters, economics of precipitation, and production plans for chemical processing solutions and rinse waters were also presented.

The feasibility of recycling certain categories of water used in the manufacture of airplanes was demonstrated (554). Water in four categories was continuously recycled in 380 liter (100 gallons) treatment plants. The four categories were: chemical process rinse water, electroplating process rinse water, dye-penetrant crack-detention rinse water, and machine shop water based coolant. Capital and recycling costs were estimated for each category.

Hicks and Jarmuth (555) reported on a regeneration process that was conceived and tested to reduce the frequency of discarding spent chromated deoxidizers used extensively in the metal finishing industry. Engineering techniques in this project involved reoxidation of trivalent chromium to the hexavalent state by electrolysis through a diaphragm plus removal of undesirable dissolved metals by crystallization and separation. Results of the tests established that regeneration of chromated aluminum deoxidizers is feasible, practical, and economical.

Hayashi (556) described a method for the recycle treatment of chromium plating wastewater. The process is characterized by the treatment, under neutral conditions, of the chromium plating wastewater, from which the iron and other metallic components have been removed by the addition of sodium or calcium hydroxide followed by precipitation, and by the subsequent adsorption of sodium or calcium with cation resins before the adsorption of dichromic acid ions on the anion resins.

A patent has been issued for a process for removing and recovering chromium from wastewater by direct precipitation of chromium using barium carbonate in aqueous solutions acidified with glacial acetic acid at a preferred pH range of 4.5 - 4.7 (557). Hashimoto and Shiraishi (558) reported on recycling chromate-bearing wastewater from plating by using submerged combustion.

The ISIS system of wastewater treatment was introduced in 1972 by the H.D. Jackson Company, Ltd., as a fully automatic method for the metal finishing and allied industries (559). The system consists of individual modules which allow for a high degree of flexibility. The modular units are: pressure vessels; powered valve capsule; sequence controller; and pH controller and recorder. This system is used for boiler water treatment at the Willenhall Works of Albert Monston and Company Ltd., a manufacturer of aluminum products anodized at their own plant. The installation, although complete in itself for boiler water treatment, forms the nucleus of a plant which is to be extended to handle future demand for treatment of final rinse water, sealing water, and vat makeup for the anodizing plant, and ultimately provide reuse and recirculation of the effluent.

Metal treating plants which pickle iron generate large volumes of acid rinse water containing high levels of iron. It would appear that use of the modified Desal Process described by Kaup et al. (560) would allow reuse of the rinse water in a closed cycle operation. Cost of such treatment would depend on the sulfate level, pH, and iron content of the rinse water.

Chemical rinsing of electroplated parts and batch chemical treatment of spent processing solutions have been demonstrated to be a practical approach for abating pollution at a small metal finishing facility (561). The treatment system reduced heavy metals in the wastes to a level where substantial quantities of water could be reused.

Lewin (562, 563) discussed water usage, reuse, and effluents from motor assembly and the metal finishing processes in the motor industry. Water usage and associated trade effluents in relation to car production were illustrated. Several examples of water conservation practices for cooling waters and process waters were presented. These included introduction of closed-circuit cooling systems, private cooling towers, or even heat exchange with refrigeration. Waters used for filling radiators and tank testing were diverted as makeup for such systems instead of being wasted.

The Lancy method for purification of wastewater from metal surface treatment industries was discussed by Ishiyama (564). The method utilizes chemical rinsing processes which are incorporated into the metal surface treatment processes. Processed metal surfaces are cleaned at the end of each process by chemical reagent rather than with water; therefore, the chemical cleaning process could be made more effective by choosing the appropriate chemical reagent for each manufacturing process and unnecessary water rinsing could be considerably reduced. As much as 97 percent of the rinse water required in most of the metal surface treatment industries could be saved if the Lancy method is used. Water used in the final rinsing step would have a less complicated chemical composition, facilitating purification for water reuse.

There are several methods of liquid-solid separation available for treating metal finishing wastes (565). Direct pressure filtration was the most efficient method discussed. With properly prepared wastes, complete liquid-solid separation can be effected through a pressure filter. The ultra-high clarity filtrate can be reused. Rising water and sewer costs make it desirable and economically sound to consider pressure filtration for treating metal finishing wastes.

A wastewater treatment plant consisting of a collection sump, equalization basin, iron contact launders, copper settling pots, clarifier, thickener tank, and control building was constructed to treat spent acids from a brass mill (566). Treated effluent is reused as cooling water in the plant.

Data General Corporation, Southboro, Massachussetts received a patent for a water recycle treatment system comprised of two main treatment subsystems to separate out the impurities in contaminated water from concentrated solutions and rinse baths (567).

Metal surface finishing wastewaters often contain quantities of toxic materials, including cyanide (568). One method of eliminating cyanide is ozonation. The process of ozonation can be performed continuously with the purified water recirculated as service water.

Treatment of metal finishing wastes involves cyanide destruction. A process involving ozone has been developed that completely destroys iron and nickel cyanides (569). A small amount of artificially produced ultraviolet light is used to free cyanide so that it can react with ozone. The process, called UVOX, may be adopted for plating effluents of varying concentrations. Cyanide removal is followed by chemical precipitation to remove heavy metals to below EPA specifications. Advantages of the UVOX process were outlined. Resulting effluent quality is high enough to recycle at least 80 percent of the effluent, thereby saving on rinse water costs.

Abe and Hanami (570) described treatment of cyanide compounds in metal plating wastewater by the impact method. The operation is based on formation of hydrogen cyanide from metal cyanide compounds by adjusting wastewater pH with sulfuric acid. Recovered metal cyanides can be reused in the plating bath solution; the filtered solution can be reused as the rinsing solution in the plating process. Thus, a closed system of plating wastewater treatment is possible.

The feasibility of using solvent extraction for removal and recovery of cyanide and zinc from electroplating wastes was investigated in a laboratory scale continuous mixer-settler (571). Quarternary amines were used to extract the zinc and cyanide wastes, and regeneration of the amine solvent for recycle was achieved by stripping it with dilute sodium hydroxide. The process yielded two useful products, the decontaminated water and a sodium hydroxide concentrate containing the recovered chemicals.

Erwin (572) described a closed-loop system which separates oil from the prewash rinse water of the aluminum can finishing process at the Miller Brewing Company. Ninety percent of the oil can be removed by this closed system which also provides for the recirculation of water. Advantages of this system are reduced water and chemical consumption and recovery of oil for reuse or sale.

Wild and Hirschmann (573) indicated that recycling may cause some adverse effects on the electrodisposition process if proper control is ignored. Without proper control of pH valves and cyanide content, it was suggested that adverse effects would result on nonferrous metal and bright nickel dispositions.

The technique of desalination by freezing is eminently applicable to the treatment and recycling of metal-plating wastewaters (574). Its main advantages include low-temperature operation, low energy requirements, avoidance of membranes and other surfaces, and no volatiles carry over. A schematic description of the freeze-concentration and recovery process is presented and its operating parameters and economic aspects are discussed.

Stepakoff and Siegelman (2) gave a process analyses of a closed-loop metal plating waste-rinse system with an electric freezing unit supplying reclaimed fresh rinse water, makeup water for the plating tank, and a concentrated slurry of plating tank chemicals for reuse in the plating process. Preliminary economics of the process were also presented.

PULP AND PAPER AND ALLIED INDUSTRIES

The recycling of process waters has been a traditional practice in the pulp and paper industry (575). In some instances, this practice is dictated by shortage of water, but primarily has been adopted because of the economic advantages resulting from it. These are namely fiber, filler and chemical savings, heat recovery, and where its cost is high, conservation of water itself as well as effluent control. Economic reasons have probably had the greatest effect on present day practices and are indeed the initial reasons for recycling process wastewaters. The author has presented an excellent overview of water reuse in the pulp and paper industry with the discussion limited to practice for the most common operations of the industry, namely kraft pulping and bleaching and production of the more common grades of paper and paperboard from the pulp.

The Federal Water Pollution Control Act ammendments of 1972 declared the National goal to be that the discharge of pollutants into navigable waters be eliminated by 1985 (576). A kraft mill, for example, will require a combination of reduction of wastewater generation, maximizing reuse of wastewater streams, and development and application of new treatment techniques. Among the process measures which look promising to reduce wastewater discharges are: increasing pulp washing efficiency, closing down stock screening, oxygen or other bleaching, increasing dilution in washing, stripping condensates, collecting chemical spills, collecting fiber spills, and dry barking. It may be possible to maximize reuse of wastewater streams and recover chemicals.

The impact of 1983 discharge limits on existing mills in the pulp and paper industry was summarized by Rath (577) with reference to in-plant conditions and reuse potential of treated wastewater. In-plant reduction of wastewater volume is beneficial in reducing total effluent of suspended solids, lowering capital cost of new treatment facilities, and providing production cost savings, and is essential for stable operation of an activated sludge plant. Treated effluent reuse potential for most integrated mills is in the range of 5-20 percent of total mill water requirements. Additional treatment to the 1983 discharge compliance level will not significantly increase suitability of final effluent for reuse.

Common sense and environmental concerns dictate that water should be reused as often as possible (578). Benefits from a closed water circulation system in paper mills include conservation of fresh water, chemicals, and heat, and reduced volumes of discharged effluent. Problems associated with water reuse may include machine operating difficulties such as corrosion, scale and microbiological deposits, pitch troubles, and algal or bacterial slimes. These problem areas were discussed, and possible countermeasures were indicated.

According to Gossum and Sager (26), the most likely way the paper mill industry will solve its wastewater problems is through recovery and reuse of water, rather than treatment. A water management plan with emphasis on water reuse and product recovery was presented on a papermill which processes waste scrap paper into paper used in the manufacture of wallboard liners. Operating data illustrates how this plant is able to meet EPA effluent guidelines with minimum end-of-pipe treatment due to an effective water management plan.

Thibodeaux et al. (579) noted that the paper industry is one of the largest users of water and produces wastewaters high in pollution content. Treatment of these wastewaters so that they could be reused in the mill was the focus of this study.

The most logical first step toward reduced pollution at a pulp or paper mill is to maximize water recirculation and thus cut freshwater intake (580). This will both simplify the task and lower the costs of removing suspended solids and BOD from effluents.

Recycling of process waters is the best approach to reduction of effluent volumes in pulp and paper mills (581). Increased reuse of water requires improved measures for controlling deposits of a microbiological nature, such as slime growths, and of nonbiological deposits, such as scales. These deposits can cause losses in production, losses in heat and raw materials, reduced life of paper machine felts and wires, and reduced product quality.

Closed-circuit processes have been used in the pulp and paper industry as a means of reducing the quantity of wastes requiring disposal and of recovering valuable substances in the wastewater (582). Waste treatment at a paper/board plant can involve primary treatment for recovery of water to be used in feed preparation; secondary treatment for recovery of fibers, fillers, and additives; and tertiary treatment for reuse of the residual effluent. Advantages and disadvantages of adding tertiary treatment were discussed.

Edde (583) presented a brief history of pollution control efforts in the paper industry. Comments were made on several novel treatment methods for obtaining high-quality effluents for process water reuse. Bush (584) defined the concept and implementation of the closed paper mill system, pointing out advantages and updating progress made by the industry in achieving this goal. Examples of closed mills were given and associated problems enumerated. Billings (585) presented a critical analysis of problems involved in increasing internal reuse to develop a closed water system in the pulp and paper industry.

Gottsching and Dalpke (586) described the fundamental principles of paper-mill closed water systems. Effects of higher concentrations of inorganic salts and/or organic solutes on paper quality were considered. The water condition and products quality were reported for a tissue mill which has been operating with a closed circuit for a long time, with an average discharge of one cubic meter of water per ton of product.

Brecht and Dalpke (587) presented a critical review of the literature reporting experience with the closing or partial closing of process water circulation systems in paper mills. Included were discussions on the planning and engineering stages involved in circuit closure, its advantages for pollution abatement, and its disadvantages or problems.

The closure of pulp mill water circuits is attractive for several reasons, including pollution abatement, freshwater conservation, and reduced fiber losses (588). Key points in closed production lines and some of the attendant problems were discussed.

Alexander and Dobbin (589) discussed the use of a closed mill water system as a means of pollution abatement for the pulp and paper industry. Closure of the paper mill water system eliminates the need for extensive secondary and tertiary water treatment facilities. However, closure may allow concentration of dissolved solids in mill water to be drastically increased through water reuse, possibly affecting water quality and paper properties. At complete closure the concentration of dissolved solids in the headbox can be up to 160 times the level anticipated for a completely open mill.

Although the paper industry uses large amounts of process water, only about 10 percent is actually consumed in the papermaking process (590). Since much of the polluting load of a paper mill effluent results directly from the presence of raw materials in the water, there is a strong economic incentive to recover these materials and recycle them. This has led to an increasing use of recovery systems in the paper-machine white water system. Three devices for recovering suspended solids were discussed including gravity settling chambers, floatation devices and mechanical filters. When discharge requirements become very stringent, there are strong incentives to increase primary in-plant treatment, reduce process water requirements, and increase water recycle rates. All of these steps approach the ideal goal of a totally closed mill system and reduce pollution.

Roberts (591) reported that efforts to stem pollutional effects of paper mill effluents in England have taken two courses: conventional treatment and water reuse. Since paper mills must pay for water and water must be conserved like any other resource, a system of recirculating water within a plant has been instituted. This has reduced the loading on treatment plants thereby reducing treatment costs. Water reuse has also alleviated the sewage fungus problems in rivers downstream from paper mill outfalls. New machines have been designed to accept reused water and show great promise in increasing benefits from this concept. Effluent purification is expensive and gives no return on capital. In-plant recovery of water results in substantial savings and provides for a better effluent.

Resource scarcity, environmental constraints, and economic factors were noted as the principal reasons for water reuse in the Australian pulp and paper industry (11). These reasons were examined and water reuse practices were described. Equipment and processes utilized to prepare the water for various recycling processes were shown to vary with quality and environmental requirements. Examples of water reuse systems utilized by Australian Paper Manufacturers Ltd. mills were included, and some problems associated with water reuse were discussed. The future of water reuse in the industry was considered.

The concept of waste-free technology in the pulp and paper industry, as defined by the Commission on Economics of the European Common Market, was discussed by Tipisev et al. (592), and measures already introduced toward this goal at Russian mills were indicated. Measures aimed at reducing consumption of fresh water include dry barking, diffusion washing of pulp, screening and beating at high consistency, manufacture of paper by the dry process, and purification and recycling of fiber-containing effluents. The proposed conversion of the Selenga pulp and board mill, located near Lake Baikal (USSR), to entirely effluent free operation was discussed.

Environmental protection of waterways from paper mill discharges can be achieved by closing the white water circuit of paper machines (593). Swedish experience with a closed-system newsprint machine has indicated that at least part of the normally discharged pollutants can be recycled and included in paper products without detriment to their quality. Some properties, such as optical and mechanical characteristics, can actually be improved. Moreover, savings in fiber and heat consumption can result. Operating conditions of paper machines must, however, be carefully adjusted and monitored.

In order to limit environmental pollution, many paper mills in West Germany are adopting the closed-water system of production using recycled water (594). The closed system offers savings in water and energy. Its use with the alkaline hydrolysis process allows recovery of valuable by-products such as pentoses and hexoses.

Results of a survey of environmental protection measures being used by pulp and paper mills in Austria have been presented (595). Emphasis has been placed on reduction of air and water pollution by technological improvements, closed-cycle processes, and other measures which permit partial recovery of chemicals rather than on the treatment of effluents.

Wernquist (596) discussed recent technology developments by the Swedish pulp and paper industry in preventing water and air pollution. Closed-circuit pulp screening and purification of condensate, along with dry barking and an improved pulp washing method, has resulted in a nearly completely closed system in a modern mill up to the bleaching stage. Presently, bleaching is responsible for nearly 70 percent of mill-caused pollution, and efforts are being made to develop suitable processes for purification of bleach plant effluents.

Coats (597) reported on water conservation measures in the design of new paper mills. It was determined that specific reuse was essential. Typical demands and methods of economy were described for mill water systems, including reuse of cooling water, gland seal water, vacuum pump seal water, and press felt cleaning water. A closed white-water system was deemed essential to water economy. Examples were given of typical white-water chest designs for efficient system purge and maximum white-water reuse.

Springer (598) reported a study program devoted to the development of information which would be useful to mills in implementing programs of more extensive water reuse in high quality paper manufacture.

Increased reuse of paper machine wastewaters seems desirable both from economic and ecological viewpoints (599). Three continuous trial runs were conducted on the 30-inch wide fourdrinier machine at Western Michigan University with 72 percent versus over 97 percent reuse of white water. Increasing system closure from 72 to 97 percent water reuse did not seriously effect the quality of manufactured paper. After several minor changes in equipment and operating procedure, the paper differed only negligibly in strength properties, dirt content, and printability.

Due to rising energy costs and environmental constraints, efficient reuse and recycling of waste streams at kraft pulp mills can be advantageous because it can reduce overall water consumption, minimize effluent volumes to be treated, and optimize low-level heat recovery, thereby decreasing steam usage (600). Quantitative and qualitative methods used to design an efficient water reuse system were analyzed, and examples were given of alternate modes of unit process operations and how they can affect the overall water, steam, and effluent streams.

One possible way to reduce discharge of water pollutants from kraft mill bleaching is to recycle effluent streams from the bleach plant to the recovery system (601); however, this raises questions concerning effects of increased chloride levels in the liquor cycle and removal of chlorides from the recovery system. These workers conducted mill trials to determine the distribution of chlorides between the smelt and gas phase in the recovery furnace and correlated the distribution with a theoretical chemical process model. Implications of these studies on operating conditions of the recovery furnace were discussed.

Recycling bleach plant effluent to the recovery system reduces the amount of water pollutants from a bleached kraft pulp mill (602). It was reported that several methods of removing chlorides from a mill with a closed bleachery were under development. Extended delignification in the cook, oxygen bleaching, and the use of a high proportion of chlorine dioxide during bleaching will help keep chloride levels low.

Haynes (603) reported on the evaluation of a number of processes for water recycling possibilities in the pulp and paper industry. Systems were evaluated on the basis of incentives for process installation. This analysis was carried out on departmental and mill wide scales. The latest water recycling values were analyzed. The evaluation indicated that reported values for recycling are probably low, thus, a new mill installation with the emphasis on practical recycling schemes shows a reuse factor of up to 1600 percent for a bleached kraft pulp mill. The all industry recycling value last reported was 290 percent.

Water and air pollution in the kraft pulping industry were discussed by Miller (604). A kraft mill uses 15,000 to 25,000 gallons of water for unbleached and 15,000 to 60,000 additional gallons for bleached pulp. Sedimentation, aerated basins, and activated sludge are the main external effluent treatment methods; however, particulars of water-reuse systems vary from mill to mill.

Hammar and Rydholm (605) outlined papermaking operations of kraft or sulfate-process pulp mills and evaluated them with regard to their water-polluting aspects. Among recent technological developments holding considerable promise of abating pollution are the trend toward higher yield pulping processes, especially semi-chemical processing; improved pulpwood digestors combined with countercurrent pulp washers for increased recovery of black liquors; bleaching with oxygen resulting in low BOD bleach plant effluents; and water recirculation for fiber recovery and attendent reduction of suspended solids. Chemical recovery from black liquor via evaporation, combustion and causticizing of the dissolved smelt was also addressed.

All aqueous effluents from bleached kraft pulp mills can be eliminated by recovering and reusing all water and chemicals required for bleaching (606). None of the process changes that would be involved would be radical departures from existing technology, and none of the equipment needs are novel. The design and development status of effluent free kraft mills is discussed in light of these possibilities.

Narum and Moeller (607) described a four part program initiated by Simpson Paper Company to improve wastewater treatment at its integrated bleached kraft pulp and paper mill near Anderson, California. The program included greater internal reuse of process water, upgrading existing primary treatment facilities, a new low rate aerated stabilization basin as a secondary waste treatment system, and use of the secondary effluent for irrigation of grain crops.

Developments in pulp bleaching are strongly influenced by the need to utilize existing equipment and to minimize water and energy use in old mills, and to reduce capital and energy expenditures in new facilities (608). Countercurrent reuse of wash liquors can reduce effluent volumes perhaps as much as from 20,000 to 4,000 gallons per ton of pulp. Diffusion bleaching promises to reduce this further to about 2,600 gallons per ton with similtaneous reductions in stream consumption and pumping energy. The effluent-free bleached kraft mill concept promises to find realization in the Rapson-Reeve system currently undergoing practical trials.

Rapson and Reeve (609) outlined the required processes and process changes necessary to make bleached kraft pulp mills free of liquid effluents by recovering and reusing all water and chemicals used for pulping and bleaching.

The Continental Can Company of Hodge, Louisiana, initiated a modernization and expansion program for better water pollution control at an unbleached kraft and semi-chemical pulp and paper mill (610). A large scale color removal system was designed from criteria established in laboratory and pilot plant facilities. New standards for unbleached kraft waste effluent treatment were also developed. Water consumption was reduced by 30 percent through recycling and utilization of the color removal system to further reduce BOD in the waste effluent. The total investment necessary was determined to be less than two-thirds the cost of constructing a new plant of equal capacity.

An outstanding example of the use of advanced techniques for the control of air and water pollution is exemplified at the American Can Company plant for the manufacture of kraft pulp, paper and tissue products (611). Processes were selected for incorporation in the extensively automated plant that minimized odor production and which facilitated the use of recycled water. The wastewater treatment system consists of a primary clarifier, two aerated ponds, secondary clarifier, and chlorination basin.

A description of the wastewaters treatment system installed at the Bridgeview, Illinois, container plant of St. Regis Paper Company was given (612). Pollutants are precipitated with chemicals, filtered from the water, and disposed of in a sanitary landfill. Treated water is decolorized in an activated carbon column and either reused in the container plant or discharged to the municipal treatment system.

Timpe et al. (613) presented a survey of the literature and other sources on the handling and treatment of pulp and paper mill effluents, with particular emphasis on the kraft process, and the use of activated carbon and lime treatment as advanced methods of treatment. The survey was made as a first step of a development program aimed at maximum water reuse in kraft pulp and paper mills based on effluent treatment using activated carbon. Results of the survey include information on activated carbon and its application in treatment of pulp and paper mill effluents. Information is presented on lime treatment of kraft mill and other advanced methods. The subject of in-plant water reuse is also covered.

Ishii (614) described antipollution features at Oji Paper Company's kraft pulp and paper mill in Japan. Paper machine white water is filtered or passed through savealls for recovery of suspended fibers, clay filler, and other solids and then into in a 24-meter diameter clarifier. The supernatent is recycled as condenser cooling water. Installation and operating costs of all pollution control facilities are listed.

An environmental improvement program has been completed to supplement existing treatment facilities at the integrated kraft pulp and paper mill and converting plant of Thilmany Pulp and Paper Company, Kaukauna, Wisconsin (615). The installation comprised both external and internal treatment measures. Internal water conservation measures include an extended white water collection system, high-pressure machine cleaning showers, reuse of decontaminated evaporator condenser water, and fiber-recovery savealls. External treatment involves a clarifier basin, centrifugal sludge dewatering system, and two biological oxidation lagoons. A flow chart of the entire system including auxillary equipment, is included.

Renovation programs in two existing kraft mills have demonstrated that increased water reuse and recycle within conventional bleach plants can reduce steam and fresh water consumption and effluent volume. The design for new kraft bleach plants incorporated not only chlorination filtrate recycle and complete countercurrent washing, but many other steam and water saving features. All the bleach plant filtrate can be recovered and the last major source of water pollution from bleached kraft pulp mills eliminated (616).

Warnquist (617) discussed reduction and control of pulp room effluents and sulfur dioxide emissions from the recovery furnace in bleached or unbleached kraft mills by system closure and by internal measures. In-plant solutions for reducing the large fraction of organic compounds in the screen room effluent include extensive brown stock washing, recycling the decker effluent to the screen room, screening at high pulp consistency, and in-line refining with minimum or no screening. A Norwegian integrated mill was described which produces kraft pulp for bag paper and linerboard with in-line refining without screening. A proposal to close the system suggests that the drum filter effluent be reused counter-currently in the high-heat washer and that a radial washer be installed after the refiner to increase chemical recovery.

Nicholls (618) discussed development of closed-process technologies for kraft mill multistage bleach plants. He noted that treatment of bleaching effluents adds significantly to production costs. Alternative in-plant treatments comprise reductions in bleach plant volume and two engineering approaches to oxygen bleaching: recirculation of bleach effluent in the pulp mill system, and oxidative pulping bleaching. If bleach plant effluents are to be recycled, their volume must be reduced, perhaps by reverse osmosis concentration, and their chloride content must be eliminated.

The large effluent volumes from a conventional brown stock screen room in a kraft mill can be reduced by recycling the decker effluent, by screening at high pulp consistency, and by in-line refining with minimum or no screening (619). Closed handling and treatment of coarse screen rejects can be accomplished by recooking or refining and recycling of rejects. Cost comparisons were made for in-plant measures to reduce effluent volumes versus external treatment and for the options for closed rejects handling.

Burkart (620) conducted experiments in which the wastewaters from the alkaline extraction stage of a pulp bleach plant was recycled in order to study the effects of recycling on the quality of bleached pulp and on the color or ease of decolorization of the resulting, more concentrated effluents. Results indicated the pulp required no increased consumption of bleach to achieve the desired brightness, and that lignin in the recycled alkali-extraction water is readily precipitated, leaving an amber-colored supernatent that can be further decolored with activated charcoal or bleach, if necessary.

Black liquor evaporator condensates, raw mill effluents, and chemically or biologically pretreated aqueous wastes of the Baikal kraft pulp mill (USSR) were subjected to reverse osmosis in comparison with ultrafiltration, using soviet-made cellulose acetate membranes (621). Both methods of effluent treatment recovered water of sufficient purity for recycling as pulp mill process water. Ultrafiltration was found to operate more efficiently at relatively low pressures; whereas, reverse osmosis was superior in removing dissolved mineral compounds.

Engelhoffer (622) indicated technological and economical advantages of white-water clarification by flotation for treatment of recyclable water and final effluent and noted the successful experience at four paper mills. Scharsmied and Slanina (623) discussed the need for, and problems associated with, recycling white water and effluents in the pulp and paper industry, particularly the complex nature of deposit and corrosion problems.

Berger and Wilson (624) reviewed the status and possibilities of wastewater reclamation and reuse in the kraft pulping industry. Ranhagen (625) presented models for closed-water systems integrated with an air emmission control system for a kraft pulp and paper mill. He concluded that a closed system is a realistic possibility.

Ranhagen (626) discussed present and future ways and means for closing integrated paper mills for air and water pollution control. Particular aspects covered included changes in pulp washing, chemical balance control, treatment of contaminated condensates, and integration of mill operations to reuse water. Diagrams of a closed kraft and ground-wood mill and theoretical aspects of washing systems were presented.

Countercurrent washing for pulp from the bleach stage of kraft mills is one proposed system of pollution abatement (627, 628, 629). Laboratory work on this method has indicated the effectiveness of this system. Effluents from the acidic and alkaline sewers of a bleachery using the D(C)EDED sequence to bleach can be reduced approximately 10-fold by extensive chlorination filtrate recycling and countercurrent washing. The system may be used as a separate bleach plant effluent treatment or for bleach chemical recovery.

Histed (630) reviewed countercurrent pulp washing practices of 20 Canadian and U.S. kraft mills. Details, including flow charts, were presented with emphasis on water needs and recirculation problems. Cornell (631) described a closed-cycle bleached kraft pulp mill using a salt recovery process. Complete countercurrent washing in the bleach plant reduced water usage by eight percent.

Armstrong (632) discussed the $10 million energy and environmental improvement program at the Abitibi bleached kraft pulp and stud mill in Smooth Rockfalls, Ontario. Effluent from the pulp mills screening operation plus fines from the bark screen room are processed by an Eimco Envirotech effluent clarifier. Recycling water from the clarifier and countercurrent washing in the bleach plant have cut water consumption to 44,000 gallons/ton of pulp.

Stevens (633) described a white-water recirculation system for a papermachine producing various grades and colors of kraft specialty papers. The system uses a disk filter to clarify the white water with recirculation of the filtrate to the machine showers and the filter showers.

With presently available equipment and other methods, complete recycle of condensate in a kraft mill can be achieved while reducing BOD by 75 percent (634). Capital and operating costs of such a system and methods for reducing operating costs were presented.

Lowe (635) described the effluent treatment system at the Gulf States Paper Corporation 100 ton/day kraft mill in Tuscaloosa, Alabama. Combined effluent from the pulp and paper mills is clarified in a primary clarifier, treated in a 4-stage UNOX activated sludge plant, decolored by reacting with alum mud, and finally clarified and discharged to a holding lagoon. Gulf States eventually plans to reuse most of the purified effluent.

A description was given of the 700 ton/day bleached kraft pulp mill of Great Lakes Paper Company, Thunder Bay, Ontario (636). The closed-cycle process consists essentially of recycling bleach plant effluent through the standard black liquor recovery cycle and from the resulting white liquor separating out the salt which becomes the basic raw material for manufacture of chlorine dioxide. Flow sheets of the closed-cycle recovery system, salt recovery process, and pulp screening, cleaning and bleaching operations were included. Benefits of the closed-cycle mill were noted. Savings in operating costs for the mill were detailed.

The closed-cycle bleached market kraft pulp mill of Great Lakes Paper Company, Thunder Bay, Ontario is the first practical installation utilizing the Envirotech salt recovery process (637, 638). Savings are expected to occur from heat savings, fiber and chemical savings, water savings, reduced effluent treatment costs, and yield increases. Within 2-3 years, these economics are expected to pay for the greater capital investment compared to a conventional new kraft mill. Only 4,000 gallons of water are used per ton of pulp, about 85 percent less than in conventional kraft mills. Countercurrent reuse of filtrates plus other modification reduce steam demands in the bleaching to about 10-15 percent of those normally required. Clean clear cooling water is the only liquid discharge from the mill.

Stevens (639) discussed installation of the Rapson-Reeve salt recovery process at the 700 ton per day bleach kraft mill of Great Lakes Paper Company at Thunder Bay, Ontario. The process will remove sodium chloride from the recovery cycle, thus limiting its equilibrium concentration to a tolerable level. The process and operating equipment were briefly described. All streams containing BOD, suspended solids, color, and toxicity can be reused within the process, so that only clean water used for cooling will be discharged.

Weyerhaeuser Company at Miquon, Pennsylvania, installed a primary clarifier and storage lagoon to treat white water from five paper machines (640). The need for further water conservation prompted the startup of a pressure filter to treat and recycle a portion of the clarifier effluent. Although the full-scale plant operated less efficiently than the pre-investigated pilot unit, freshwater needs were expected to be cut by 50 percent.

Brown et al. (641) described a reverse osmosis system for concentrating white water from a paper machine, the white water having been previously freed of its fiber content through treatment in a filter or decanter. The RO unit separates fiber-free white water into a concentrate of pulp additives and a permeate. Both the concentrate and permeate can be recycled in the papermaking process, making it possible to operate a mill on a closed-water system basis.

The Mayak Revolyutsii paper mill (USSR) was to install a new effluent treatment system in 1978, in which the machine white water will flow into a storage tank and be reused in the pulpers (642). The system will increase the degree of fiber and filler recovery from 78 percent to 94-96 percent and reduce the solids content in purified water from 150 to 46 mg/liter. Recovered fibers are used in making high-quality papers. Other advantages are reduced power consumption and operating costs.

Luzina (643) described a Soviet process for manufacture of high-yield unbleached kraft pulp with efficient recycling of treated effluent water. The process is said to reduce freshwater consumption from 29.7 to 9.8 cubic meters and effluent volumes from 36.1 to 15 cubic meters per ton of pulp produced. The process features four double-chamber pulp-washing filters; a two-stage recovery of black liquor entrained with digester relief; surface condensers in lieu of barometric condensers; partial reuse of purified effluents in various mill departments; automatic water quality control for cooling of bearing and other hydraulic functions; and monitoring of water consumption and effluent discharges in all mill departments.

Fremont et al. (644) examined ultrafiltration (UF) as a means of reducing color in kraft mill effluents more efficiently and/or more economically than the presently available method. A 10,000 gpd pilot plant was operated for six months at the Champion Paper Company pulp and paper mill, Canton, North Carolina. Four experimental aspects of the process were evaluated: feed pretreatment, UF, concentrate disposal, and water reuse potential. Process color removal efficiency was satisfactory. For all influent studied, typical results were 90 percent color removal with 98.5-99 percent water recovery. Total operating costs were estimated.

Internal process control measures for controlling pulp mill pollution and reducing materials wastage include increased pulp washing, closing the brown stock screening system, new bleaching process, improved condensate handling, and spill collection (645). These measures are exemplified in recent Scandanavian installations. Overall treatment costs to meet various discharge limits in a bleached kraft mill are examined for different combinations of internal and external control measures.

Lyons et al. (646) developed a generalized mathematical model for use in determining the optimum quality of water recovery and reuse. The model and associated methodology were applied to the water management system of a medium size bleached kraft pulp mill. Through optimization of this problem, the reuse of water reclaimed from industrial wastewater was accomplished by utilizing the model. The cost solution considered effects of variations in production process water quality requirements, cost and quality of freshwater and reclaimed water, and cost of effluent treatment. Application of the model to the pulp and paper mill indicated that high levels of recycle could be economically justified if stringent color standards for wastewater effluent required a high degree of biological treatment. The key to the process of reclaiming usable water from the pulp and paper mill was color removal.

An invention relating to a pulping and bleaching system in which the bleaching and extraction stages yield an aqueous acid and aqueous alkaline filtrate, and provides procedures for recycling these filtrates has been patented (647). Part of the acid filtrate is neutralized with fresh aqueous sodium hydroxide and used in washing digested pulp in a washing stage immediately prior to passing the washed pulp to the bleaching system. The remainder of the acid filtrate is introduced as an aqueous medium into the spent pulping liquor recovery cycle at a point after burning of the spent liquor. Part of the alkaline filtrate is used as wash water for washing pulp in the earlier stages of the washing system, before the stage using acid filtrate. The remainder of the alkaline filtrate is used in diluting regenerated pulping liquor to the desired concentration.

Skarsgiris and Skoupskas (648) described wastewater treatment equipment for a paper mill producing high quality printing papers from bleached pulp. Equipment consisted of six conical savealls receiving dirty water from wet presses, felt conditioning, overflows, and water used for general mill cleaning. Effluent from the clean water treatment system is recycled for process water makeup and recovered solids are sent to the hydropulpers. Effluent from the dirty water system is discharged.

The AES 3600 gravity strainer, developed in Finland, can be used to treat water for use and reuse in the pulp and paper mill (649). The filter resembles a large vertical drum with effluent flowing toward the center at about the top perimeter of the tank. The effluent flows through a distributor plate and a metal or plastic screen into a tank over which the filter is mounted. A rotating shower beneath the screen lifts, rejects and floats them toward the center reject outlet. Three applications in the United States are illustrated.

Norton (650) discussed water reuse in nonintegrated paper and board mills and the associated problems. Examples were given of closing the water system on a multi-ply board machine and of water conservation on a fine paper machine.

Gibson et al. (651) described the wastewater treatment system which furnishes water for reuse at the Ponderosa Paper Products Inc. plant in Flagstaff, Arizona. Plant wastewater is collected at a central point and treated in a dissolved-air flotation unit. Clarified water is then put in a 3-section lagoon. From the lagoon storage basin, the effluent is polished in two automatic granular-media filters. The filtered effluent is pumped into a water tower for reuse in the mill. Operating problems and plans for improving the wastewater treatment system were discussed. Fresh water consumption at the mill has been reduced from 500,000 to 30,000 gallons per day.

A test program performed at a paper mill in Aberdenenshire area of Scotland demonstrated the ability of the Mecatec effluent treatment system to recover fiber. The Mecatec system is a multi-purpose low-cost modular unit developed in the United Kingdom (652). It has been successfully used for general and industrial wastewater treatment. The system has no moving parts and combines features of inertial and blanket filtration for effective removal of particles. The trial run showed impressive separation of thick and thin fractions. The clarified overflow was used as shower water. The thickened underflow was returned to a saveall unit achieving 400 percent increase in saveall drum efficiency. The recycled water resulted in a 50 percent reduction in mains intake. Fiber recovery should pay for cost of the system in several months.

A patent has been issued for a closed circuit paper mill effluent treatment process (653). The total effluent is collected in separate closed circuits. Part of the untreated effluent is used for pulp heating and dilution. The remainder is collected in at least one other closed circuit, regenerated by addition of chemicals, conditioned, and then supplied to the paper making process in place of fresh water. Advantages of the system include: smaller consumption of fresh water; almost complete elimination of waste disposal; no buildup of salts; and, use of a smaller quantity of expensive chemicals.

Mattison and Bier (654) described a proprietary system for recovering usable fiber from process elements. Data were cited which show that fiber recovery can reduce waste treatment cost by reducing waste treatment equipment requirements reduce fresh water requirements by permitting water that would be sewered to be reused, reduce plant maintenance requirements, and return useful fibers to process or for salt to produce income.

Akerhagen (655) described equipment for removing fiber for reuse. Fiber is separated from fines by impinging white water on a screen. Water, containing the fine fraction can be reused. The device was said to be best applied in combination with flotation. Jacobson (656) described a fractionator to classify white water for various points of reuse and exemplified its use in the production of various grades of paper and for removing solids from barker water.

One technique of recycling wastewater becoming widely adopted in the U.S. pulp and paper industry utilizes the SWECO, Inc. Centrifugal Wastewater Concentrator to remove fine particles and fiber from mill effluents (657). Operation of the equipment and a number of important pulp and paper applications were discussed. The Experience of the Horner Waldorf, St. Paul, Minnesota boxboard mill was quoted, and the cost savings achieved by resultant water recycling, energy conservation and fiber reuse mentioned.

A patent has been issued for a straining apparatus that separates fibers from backwater coming from a paper making machine so that the water can be reused as spray-water. The apparatus consists of a funnel-shaped vessel with an outlet (658). A first strainer forms one wall of the vessel and a second strainer covers the outlet of the vessel.

Folchetti (659) described the design of a paper mill waste treatment system that is integrated with the existing process water system to provide for closed loop operation to reclaim the total effluent or for operation in conventional open mode. The system consists of chemical coagulation and solids flocculation and separation in a clariflocculator, with underflow being dewatered for disposal and overflow going to the process water system.

Follea (660) described the wastewater treatment system developed for a 320 ton-per-day paper mill with two paper machines and one cooler. The system centers around a flocculator/clarifier and was specifically designed for recycling of clarified water to the mill process water.

Slightly polluted spray water from papermaking machines and ventanip presses can be cleaned by the use of Ronningen - Petter filters, arranged in units of two or more, for continuous operation in a closed-water cycle (661). In addition sealing water in vacuum pumps can be purified by means of Ronningen - Petter filters for recycle in heat exchangers. The use of these filters with backflush and snap fit gives easy mounting.

The Ukrainian State Institute for planning of pulp and paper and hydrolosis industry plants has developed several closed-water cycle systems for pulp and paper mills. Many of these systems are already in operation or are being introduced. Dubitskaya (662) described and illustrated water recycling systems operating in an electrical insulation board mill, a pulp and filter paper mill, a fine paper mill, a boxboard and corrugating medium mill, and a board mill. All systems considerably reduced freshwater consumption and effluent volume.

Effluent quality leaving the process of an integrated paper mill in Vancouver, B.C. was upgraded by internal reclaim and recycle of suspended solids from various streams including press tray water and wire return roll shower water (663). Saveall-clarified water is used for low-level makeup to the seal pit and the rich white water tank. Paper quality problems relating to the closed system have not been encountered.

McCourt (664) reviewed the use, role, and importance of post-saveall devices in providing a uniform quality water, hence enhancing the possibility for continuity of operation and more extensive water reuse in the papermaking process. Reported experience with post saveall solids devices was described. It was concluded that more detailed knowledge of capability of these devices to perform the solids separation function under variable flow and feed water quality is needed to enhance the potential for more extensive water reuse.

Stevens (665) discussed and compared saveall types and designs, white-water characteristics, objectives of a good white-water system, and factors affecting saveall design. Types of savealls described included drum, flotation, and disc filter.

Brooks (666) discussed types and technology, application, fiber and water recovery, and operational data relative to savealls. Principles of operation of the various units were presented as were operational problems. White-water systems and characteristics were enumerated. The importance of water reuse was pointed out, and the effects of closing a white-water system were listed.

Smith and Berger (667) proposed an overall treatment scheme for pulp and paper mill wastes which handles the wastewater stepwise to produce a reusable process water. A four-stage process utilizing lime dosing, biological treatment, activated carbon filtration, and demineralization was used on bleached and unbleached total kraft mill effluent. A three-stage system without biological treatment also was tested. Cost comparisons showed that reusable water would cost approximately twice as much from the three-stage system.

A sequential treatment consisting of activated sludge treatment, lime treatment, and activated carbon adsorption treatment was tested on unbleached kraft pulp mill washing wastewater in a pilot plant system (668). Activated carbon treatment of this pretreated effluent produced a colorless, extremely low COD water suitable for reuse.

A kraft plant owned and operated by La Cellulose D' Aquitaine, located at St. Gardens, France, employs a pure oxygen bleaching unit that will completely recycle its own effluent to the kraft recovery cycle (669). The unit has a bleaching capacity that completely matches the capacity of the kraft pulping unit it serves.

Koleskinov (670) diagrammed a closed system for recycling white water in the manufacture of sized papers. Freshwater makeup to the system is 1.6 cubic meters per ton. A demineralization process is included in the system. Czappa (671) described a fine paper mill operation that achieved 40 percent reduction in wastewater flow through reuse of white water and recycle of vacuum pump seal water.

Leker and Parsons (672) discussed wastewater treatment measures taken at the Masonite Corporation pulp and paper mill in Laurel, Mississippi. Wash water from steam processed pulp, containing 90 percent of the BOD but amounting to less than 15 percent of the total wastewater flow, is concentrated in a quintuple-effect evaporator. Residual solids are converted into a marketable product. Two other effluent streams containing process water plus cooling, sealing, and housekeeping waters are handled separately in primary clarifiers from which 90 percent of treated water is recycled to the mill. The remainder is treated in a biological contact-stabilization system. Overflows pass to an aerated lagoon for polishing before reuse or discharge.

Holmes (673) discussed the recycling of white water at the Powell River Division of MacMillan Bloedel, Ltd, in British Columbia. Although effluent toxicity did not increase when white water was passed through the direct-contact heat recovery unit of the thermo-mechanical pulp (TMP) plant, recycling did cause unexpected changes in pH, conductivity, and BOD. Recycled pulp mill white water is about twice as rich in environmentally deleterious material as in excess paper-machine white water. Chemical pretreatment of pulpwood chips and other TMP process variations could cause greater differences.

Closing of water systems in integrated mills is impossible as long as slush pulp enters the system at a water content higher than the web enters the dryers (674). A press capable of high tonnage and high discharge consistencies was described. This press provides an additional washing stage and allows a final assault on the objective of a totally closed water system. An arrangement of a closed system was diagrammed.

Decker and Louie (675) described antipollution systems and equipment installed at the Intercontinental Pulp Company mill in British Columbia. In-plant measures include equipment for maximum reuse of process waters and fiber and chemical reclaim systems. It is emphasised that systems such as these will not produce the desired results unless they are operated properly.

Operations and equipment of a German paper mill were described (676). The mill produces 315,000 tons of newsprint annually on four voith paper machines. Discharged paper machine white waters are treated in four scraper filters with the effluent purified chemically-mechanically in a passavant coagulator and partly recycled.

Foul condensates are collected from digester flue gases, turpentine recovery operation, and black liquor evaporators at the Nekoosa Papers Inc. kraft mill at Nekoosa, Wisconsin. After stripping, the condensate is used to heat the incoming feed and then as wastewater in the brown stock area (677). Condensates are pumped to a distillation column. The distillation column is integrated between the first and second effects of the old multiple-effect evaporators.

Methods of treating aqueous effluents from paper and board mills have been reviewed, including recycling of paper machine wastewaters, primary treatment to remove suspended solids, secondary or biological treatments to reduce biochemical oxygen demand, premixing of wastes, and treatment of condensates (678).

Model (679) described conversion of a paper and board mill to a closed water system. Effluents are treated by sedimentation and filtration. The system has resulted in elimination of a proposed treatment plant, decrease in water consumption, and recovery of solids. Disadvantages, particularly corrosion problems, were discussed.

The integrated groundwood kraft pulp and coated paper mill of Boise Cascade Corporation, Rumford, Maine, instituted in-plant water recycling and reuse systems to reduce flow, suspended solids, and BOD to the effluent treatment plant (680). A comprehensive in-plant sewer sampling and reporting program provided management with the data needed to minimize losses and to document the effect of the recycle and reuse systems. Feed to the effluent treatment plant was reduced from 45 mgd in 1972 to 23.71 mgd in September, 1977, which is five percent below Plant design capacity.

Morgeli (681) reviewed closed water cycles in paper and board mills in Switzerland and discussed problems associated with high salt concentrations and biological activity in the recirculated water. Possibilities for controlling these problems were outlined. On the basis of theoretical considerations, test results, and mill experience, three of the processes are usable in recycling water: flocculation, filtration, and adsorption. Suitably combined with biological processes, these offer a solution to the water pollution problem.

A rational basis for water reuse in paper manufacturing has been developed and applied to combination paperboard manufacture (682). The central idea of the approach is to determine the lowest quality water which can be successfully used in a given application. A water quality guideline is determined for a given water use based on that limited water quality. Water quality guidelines for a given application are obtained from actual plant data. Visits were made to 13 plants which were exhibiting good water reuse practices. These mills served as the data base for water quality guidelines for 22 water uses. A steady state water flow model for combination paperboard manufacture was developed and used to illustrate techniques the mills employed in reuse and conservation of water.

An extensive mechanical effluent purification system was put into operation at the Stupino Board Mill, USSR (683). Effluents from the board mill and auxillary plants first pass through sand traps and then to radial sedimentation tanks. Clarified effluents then undergo a second purification stage in contact clarifiers filled with gravel and layers of quartz sand of different granular composition. About 70 percent of the purified effluents are recycled to the mill as replacement for fresh process water.

Dubitskaya and Galenko (684) provided a schematic description of a water-recycling and reuse system for a paperboard mill to be added to an existing integrated pulp and paper mill at Zhidachev, USSR and a similiar system to be installed at a board mill in Rostok. Effluent from the board machine will be treated with chlorine for color removal, coagulated with alum and polyocrylamide, and passed to contact clarifiers. Clarified water will be recycled and substituted for 40 cubic meters of the 70 cubic meters of fresh water needed per ton of board produced.

The Ukrainian Board Mill in Lovov was faced with the necessity of introducing a closed water cycle because of a shortage of process water (685). The first step in this direction was an improvement in the wastewater system to increase its degree of purification. The system was described and illustratied with a diagram. Fibers recovered from two Waco filters are reused in stock preparation. Partially clarified white water goes to two vertical sedimentation tanks where aluminum sulfate and polyacrylamide are added. Purified white water can be recycled. It can be used for washing belts and cylinder mode wires.

Svitel'skii and Litvinova (686) reported on a study of water reuse at a paper and board mill processing waste paper. The study, conducted by the Ukrainian Research Institute of the Pulp and Paper Industry, showed that water reuse averages 70 percent and at some mills reaches 85 percent. Consumption of fresh water ranges from 34-80 cubic meters per ton. A purification system is described which will reduce fresh water consumption of 20-24 cubic meters per ton, reduce the pollution load by 15 percent, and allow the reuse of over 75 percent of the purified water. The system consists of separating reusable fibers on an OV-02 fractionator and treatment of the effluent with aluminum sulfate and polyacrylamide, followed by dewatering the sediment by centrifugation.

Abitibi Corporation has reactivated a 125 ton per day board mill in Blountstown, Florida. Pulping and stock refining systems designed specifically to accomodate the relatively dry raw material and to attain zero discharge are outlined (687). In general, the closed water system is comprised of a series of semiclosed loops within the system. Substantial operating cost reductions as well as compliance with water pollution control standards have been achieved with the system.

Wastewater purification procedures for two integrated board-producing/converting mills and one board-converting operation in West Germany were outlined by Morch (688). Following sedimentation, biological purification, and chemical treatment, thick-stock material from the wastewater treatment plant is returned to the mixed waste paper pulper for one of the board-manufacturing lines, while another uses chemical-mechanical reclarification plus biological treatment. The influence of recycled solids on board quality and production was also considered.

Superior Fiber Products, Inc. undertook a project to eliminate any discharge of process water from their wet process hardboard manufacturing plant through a program of water reuse (689). All but wash up water and some pump seal leak water discharges were eliminated. Water absorption and linear expansion of the board increased after close up. Close up of the process reduced chemical usage. Board strength problems were eliminated through control of the white water temperature. Some remaining drawbacks to the system are a darker board color and overall reduced cleanliness of the mill.

Starkweather and Frost (690) discussed various philosophies of achieving low or zero discharge via water recycle in paperboard manufacture and outlined operational problems encountered in several mills. Gran (691) discused the effects of complete or partial closing of the water circuit on the volume and concentration of contaminants in a paperboard mill. Various methods for treating and disposing of highly polluted effluents were considered.

Successful conversion to closed-circuit operation of a wet process fiber-board mill was first achieved in France (692). A brief description of what was done and some environmental and cost factors of recycling process water for pollution control in a wet-process building board mill were presented. Efforts to reduce pollution and recycle wastewater at a French paper mill were discussed by Vandewoestyne and Maric (693). A fiberboard factory was described that completely recovers and recycles process water with recovery of all solids in suspension.

The effluent treatment plant at the St. Anne Board Mill, Ltd. plant in Bristol, England was described (694). The treatment system consists of two clariflocculators, a sludge thickener, aerated lagoon, and sludge filter. Provision has been made for recycling some of the clarified effluent to the mill. Up to 200,000 gph of clarified effluent can be returned to the water treament plant to be chlorinated and then returned to the mill water system.

Jacobsen (695) described the change to a closed water system in a coated board mill. The system is based on recycling of process water through a sedimentation saveall. In addition to reduction in the fresh-water requirement, energy requirements were reduced, production was increased, and fiber-filler recovery was increased. Data on chemical costs, water consumption, fiber recovery, energy costs, and total costs were presented.

Panak (696) reported that water from the manufacture of wood fiberboard and from the dewatering system was partially recycled. Acceptable levels of suspended solids were maintained by vacuum filtration, and the recycle ratio was controlled so that dissolved organic matter was kept below 3 percent. Forming wire wash water was clarified and recycled separately. Only 1.7 cubic meters of makeup water per ton of product was used.

Godin (697) noted that water use and total suspended solid losses at a board mill were substantially reduced by installation of a float-wash fractionator to allow recycle of board machine white water to cyclinder and felt showers. Hammon (698) described a system for total wastewater reuse in a boxboard mill. Mill water went to a clarifier, then to sedimentation basins, and into a surge tank from which it was reduced or sent to the process water treatment plant.

Simon (699) reported the recovery of primary and secondary clarifier underflow for reuse in filler finish of a 60-ton/day board mill with no effect on product quality. A portion of the treated effluent is also recycled to the mill.

Pilot plant reverse osmosis units were operated on weak wastewaters from a pulp and paperboard mill to obtain further data on RO as an integal part of a closed water system within the mill (700). Of the many equipment types tested, the one selected was capable of concentrating a stream containing 1 percent dissolved solids to 99 percent less volume containing 10 percent dissolved solids. Product water thus separated was of high quality, suitable for use for stock dilution, pump shaft seal lubrication, etc.

Trent Valley Paperboard Mills in Ontario planned to partially close water circuits for two six-vat cylinder board machines by passing the white water through SWECO concentrators, the filtered water to be reused in felt-cleaning showers. Initial trial runs indicated that reusability of the white water was governed not so much by the quantity of suspended particles as by their size and shape (701). No significant felt plugging or picking was observed with screened white water compared to river water.

Flocculants, such as aluminum sulfate, and coagulants, such as polyacrylamide, make it possible to clarify and reuse paper-machine white waters and, ultimately, to close the water circuits of paper and board mills, especially those producing coarser grades of papers and paperboards (702).

Guss (703) examined use of totally closed water systems in board and tissue mills using secondary fiber as furnish and found that closed systems can be attained with existing equipment and techniques. Problems include corrosion, chemical and water balances, and motivating personnel to adopt new methods. Benefits include material, heat, and chemical savings; elimination of freshwater and wastewater treament costs and long-range freedom from farther pollution control restrictions. Problems and benefits were discussed. Examples of operating closed systems in various board and tissue mills were presented.

Selected, long clean saleable fiber may be recovered by the action of a DSM system for paper mills (704). The operating device is a screen comprising a series of bars with a wedge-shaped cross section. A highly detailed study was made at a large tissue mill in Pennsylvania. The full flow of the mill sewer is run through DSM units to thicken the stock after cyclone cleaning. This stock is returned to the bleach system. Cleaner rejects are added to the clarifier sludge for centrifugal dewatering and disposal. The DSM system recovers 39 percent of the sewered fiber at 5 percent consistency. Additional savings result from reuse of some of the sewered water and from reduced maintenance requirements at the flotation clarifiers.

Hubble and Bowers (705) summarized trends in white water reuse toward closed system operation in 30 European paper mills and found the degree of reuse to be greatest in groundwood and board mills. Very few mills were operating fully closed systems. Effects of white water reuse on corrosion were examined in particular, and conditions in the mills were tabulated. Bowers (706) reviewed the literature relative to corrosion of papermaking equipment in closed systems. Corrosion problems encountered as a result of white water recycling were reported. Bowers (707) examined corrosivity of recycled white water in closed systems and showed effects of pH, temperature, and chloride content.

The effluent treatment plant at the Bowater - Scott disposable products plant at Northfleet in Kent, United Kingdom, was described (708). Effluent from the mill is segregated into two streams; a "clean" stream, containing fiber from the paper making machine; and a "dirty" stream from floor drains and overflows. Each stream is fed into a contact flocculator. Alum and an anionic polymer are used as coagulants in the clean water flocculator. Water from the clean water flocculator is fed to a reusable water tank; the dirty water is discharged to the river.

The absorbent Products Division of Brown Company, Eau Clarie, Wisconsin, recycles up to 9 million gallons per day of deinking wastewater treated in a primary stage consisting of the addition of 120-150 ppm of alum at pH 6.0-6.5 and an unidentified anionic polymer (709). Flocculation was improved by the addition of 10-15 ppm of activated silica. Treatment removed 94-95 percent suspended solids and 50-60 percent BOD.

Brown Company produces 150 tons per day of absorbent tissue products. About 85 percent of its mill process water is recycled (710). Sulfuric acid, aluminum sulfate, an unidentified anionic polymer and activated silica are added to the process water prior to treatment in a primary clarifier. Recycling treated water raised the in-mill dissolved solids level by a factor of three.

Springer (711) reported results of a study of process water characteristics and water reuse practices employed in the manufacture of tissue products. A large number of such mills were surveyed. Benefits and deficits of various saveall systems were made. Problems in water conservation efforts included corrosion, plugging, slime, color, scale, and foam.

Johansson (712) described closed white water systems at a kraft mill and a tissue mill showing up to 84 percent reductions in water use. Costs savings are related to fiber recovery and reduced effluent loads. Gropp and Montgomery (713) described a tissue mill effluent treatment system designed for a minimum recycle rate of 80 percent. The process uses disk filters, polishing basins, and percolating beds.

Wisconsin Tissue Mills in Menasha, Wisconsin, installed a new effluent system in 1973 (714, 715). An EIMCO reactor-clarifier achieves primary treatment followed by a two-stage activated sludge process patterned after the Zurn-Attisholz process developed in Switzerland. Clarified overflow from the secondary system is reused in the deinking mill or in the paper mill.

The Kimberly-Clark of Canada Ltd. tissue mill in Huntville, Ontario controls pollution by a water reclamation system which recycles about 87 percent of the process water to a high-speed tissue paper machine at rates up to 2.5 mgd while reducing the effluent to about 0.12 mgd (716). The multistage water and effluent treatment involves essentially retention in a polishing basin, aeration, and filtration through twin one-acre percolation beds.

A tissue mill at Huntsville, Ontario, has been designed to meet stringent effluent quality regulations (717). A high proportion of the white water is treated in a large disk-type saveall, using magnesium hydroxide as primary flocculant, and is then recycled to the tissue paper manufacturing process. A flowchart of the water treatment cycle was given, along with a chemical description of the Kimberly-Clark patented lime process for precipitation of magnesium hydroxide.

Hartley (718, 719) reported that products recovery from wastewaters and wastewater reuse was essential in holding down costs at the Building Products Ltd. Edmonton, Canada plant. Wastewater treated in a circular clarifier and a detention lagoon is reused to the maximum extent possible.

White water from the grinder room of a groundwood mill in Mexico was purified in a clarifier basin with addition of flocculants (720). The treated water was found suitable for reuse as process water in the mill without requiring microbicidal or algaecidal additions for slime control.

Thompson (721) reviewed wastewater generation, disposal, and recycle in veneer and plywood plants in British Columbia. He reported that the wastewater can be totally recycled for extended periods of time. Frost (722) obtained a patent for an improved process for manufacture of roofing felts which involves incorporation of separated sludge into the felt and reuse of clarified water in a closed cycle operation.

Roscoe (723) considered the economics of water reuse at an integrated printing paper mill in order to meet effluent limitations and compared several alternatives. Experiments were reported concerning treatments for effluents from the pulping of straw with lime (724). Improvement in effluent quality to a level permitting reuse in the manufacturing process was achieved by flocculation of wastewater solids with phosphoric acid.

Teer and Russell (725) described a prototype wastewater treatment system and design criteria for wood preserving plants of the Osmose Company of Griffin, Georgia. Treated wastewater is reused as makeup water supplies for mixing the wood treating chemicals.

Recirculated water is increasingly being used to reduce water consumption in the paper industry. Some of its aspects were discussed by Lutz (726). A diagram was given of the Attisholz process for the water treatment system of sulfite pulp mills, and a sketch was included of the Ruthner rapid clarifier for purifying effluents. Some statistics on costs of different purification processes for effluents of various types of paper mills were presented.

A significant development has been made toward solving the problem of pollution and costs by recovering sodium base spent sulphite liquors (SSL) and marketing products produced from them (727). The spent liquor is acidified and the organic acids extracted. The residual liquor can be sold as a salt cake substitute. A flow diagram explains the many steps of the process. Basic chemistry and required equipment are also detailed. Significant results of the system are that a major portion of the chemicals required in the pulping process are reusable; no significant odors are generated from the pulping or recovery processes; recovery of sodium base sulphite pulping liquor has been tested on a plant scale; and the process is economically competitive. This system should be applicable to any independent sodium base neutral sulphite semichemical pulp mill and for sodium base sulphite pulp mills practicing full chemical cooking.

The largest consumers of water in Finland and the ones who pollute it most are sulphite pulp mills (728). A successful solution for water protection is represented by the 3-stage pulping method with soluable sodium base, employed by Rauma-Repola Osakeyhtio, who mainly produces rayon pulp. The method enables 95-98 percent recovery of the waste liquor and the regeneration of chemicals.

In-plant measures taken to reduce air and water pollution at a Swedish sulfite pulp mill were described by Brannland et al. (729). A flow diagram was presented of the Stora chemical recovery process used at the sodium-base sulfite pulp mill. The condensate is reused in the cooking liquor and for final pulp wash time in the bleach plant. Changing the bleaching sequence from CEHD to ECHD allows the extraction effluent to be returned to the recovery furnace via the screen room and unbleached pulp washing plant.

A study of freshwater usage potential at the Vetrni integrated pulp and paper factory in Czechoslovakia showed that it would be advantageous to reduce the newsprint machine effluent, after mechanical treatment, in the sulfite pulp mill (730). The only problem might be contamination of the sulfite pulp mill system, mainly the spent liquor evaporators, with sulfite ions originated in the paper mill. Results from computer simulation of the proposed recycle showed that the sulfite ion concentration would not reach a dangerous level when the newsprint paper mill effluent is used in the separation section of the sulfite pulp mill.

Properties related to combustion, chemical recovery, and reuse of recovered chemicals and relief liquors from waste liquors in magnesium-based semichemical pulp production were investigated by Chou et al. (731). Production methods assessed were the vapor-phase magnetite, magnetite, slurry, two-component, and high-yield sulfite processes. Reuse of recovered chemicals presented no problems, except for the relief liquor of the vapor-phase magnetite method. Results indicated that the vapor-phase magnetite and liquid-phase magnitite methods were more beneficial than the others. Because the former has the additional disadvantages of a longer cooking time, the latter may be the best method available.

In many Scandinavian sulfite mills, SSL evaporation condensates are recycled either to the cooking liquor preparation or to the pulp washing stage (732). Two possibilities for internal reuse were proposed: 1) untreated condensates might be reused in the bleach plant; or 2) partial purification by anion exchange would reduce the BOD by 50-60 percent and the COD by 70-75 percent, so that treated condensates could be used in lieu of fresh water for pulping and pulp washing without adverse effects on pulp quality.

Nelson et al. (733) described the pulp and papermaking operation at the Green Bay, Wisconsin, neutral sulfite semichemical mill. Generation and distribution of solubles in the process and excess waters of the mill were also discussed. The operation consists of mill sewers, recycled water flows, spill surge flow, and internal monitoring control system. Wastewater handling with a proposed reverse osmosis operation was detailed.

Green Bay Packaging Company operates a tightly closed neutral sulfite semichemical corrugating medium mill at Green Bay, Wisconsin (734). An essentially closed white water system, liquor combustion plant, white water surge storage system, and full-scale reverse osmosis unit are integrated in such a way that steady operation is expected to result in less than 5 pounds of BOD per ton of pulp in the mill discharge. Some difficulties with the membrane support structure have been experienced.

The rationale and methodology of the in-plant waste control system at the Green Bay Packaging, Inc. semichemical pulp and paperboard mill in Green Bay, Wisconsin were presented by Morris et al. (735). The system includes a RO plant to maintain volumetric control of reused process waters. The RO plant design and operating performance were described. The effort to reliably maximize the reuse of excess water and to define the capability of RO as a tool for controlling reuse volume were the goals of this project (736).

Kunzler (737) described pollution abatement measures instituted at a sulfite paper mill to reduce effluent load and application of clarification to the effluent with recycling of some of the clarified effluent. Akim and Bystrova (738) described a process for manufacture of sulfite dissolving pulp in which cooking liquor is prepared from spent liquor of oxygen - alkali refining, and other liquors are reused resulting in drastically reduced effluent volumes.

A theoretical calculation was made of the effects to be expected in sulfite pulp mills in which spent sulfite liquor is neutralized and recycled to the wood digester along with recovered evaporator condensates obtained at different liquor pH and with varying degrees of condensate reuse (739). Complete closing of the liquor cycle was found to be impossible because the volume of condensates exceeds the water demand of the acid-making system. Excess condensates may conceivably be reused as wash water in a sectional spent liquor recovery system with a major portion being introduced into the dilute liquor while a minor portion would accompany the washed pulp and be lost down the screen room sewer.

Process modifications made at the ITT Rayonier pulp mill, Fernandia, Florida, to reduce wastewater discharge from the sulfite pulping process were discussed (740). Conversion of the pulp bleaching process from an ammonia-based cooking cycle to a soda-based cycle allowed for direct recovery of many digester wastes as solids rather than liquids, with the result that they can be incinerated for full value. The process change resulted in a decrease of BOD in the plant raw water loadings of about 90 percent. Overall costs of the modifications were quoted as $38 million in 1972 dollars.

A reverse osmosis pilot unit at the institute of paper chemistry was used to concentrate dilute pulp wash waters obtained from a nearby pulp mill where a high-yield sodium sulfite semichemical pulp had been dewatered in a screw press (741). At elevated temperatures (about 45°C), the problem of membrane fouling was alleviated. Continuous operation of the RO unit in conjunction with the screw press, gave 90 percent or better recoveries of dissolved liquor solids. Clear water obtained was of sufficiently high quality to be recycled to the process stream of the pulp mill.

Claussen (742) described ultrafiltration and reverse osmosis modules developed by a Danish company for treatment of pulp and paper mill effluents. Purification of SSL by UF and RO treatment of dilute SSL and wash waters were discussed. A RO plant has been operating at a Norwegian sulfite mill since September, 1976. The plant processes 14 cubic meters per hour of dilute SSL. The permeate is reused in the bleaching plant for neutralization after the hypochlorite stage. Suggestions were offered for using membrane filtration equipment as parts of larger integrated systems for treatment of pulp mill effluents. Data were presented showing the mass balance concentration data capacity and cost of UF and RO treatment of SSL using coarse and dense filtration membranes.

A waste treatment process which involves contacting a waste effluent with a metal salt reagent, preferably alum mud, has been patented (743). The method is applicable for treatment of pulp and paper mill wastes. Effluent is oxidized, and a substantial portion of the organic content is precipitated. The decolorized effluent is bio-oxidized in a multistage sequence and subsequently is sufficiently pure for recycle purposes. The purified effluent may also be bleached prior to recycle.

Laboratory evaluations of twenty resins and seven carbons showed that resins were equal to carbon for decolorizing the combined waste from a four-stage kraft bleach plant (744). With few exceptions, resins were unsuited for decolorizing wastesrom each stage separately. Single stage ion exchange produced water adequate for unbleached pulping. Two stage desalination produced water adequate for bleached pulping. Any of the continous counter-current ion exchange processes are probably adequate for producing water for bleached pulping.

Davis et al. (745) reported that sand and gravel pressure filtration improved the quality of primary clarifier effluent to the extent that the filtrate could be used as process water in the manufacture of printing and other fine papers. The filtered water is further improved by adding an amylase enzyme to destroy the dispersant power of cationic starch present in the white water, and be treatment with chlorine to prevent slime deposits.

Reeve (746) presented a review of the literature on sodium chloride (NaCl) in alkaline pulping and chemical recovery. The history of NaCl accumulation in recovery systems, and methods available for NaCl control and removal were reviewed.

Mulford and Cooke (747) reported and evaluated 16 methods of reusing vacuum pump seal water. These were grouped into three categories in order of preference: a) freshwater supply with reuse after the vacuum pumps; b) reuse of previously used water; and c) recirculation of seal water.

Dickbauer (748) examined effluent problems in the corrugated board industry and pointed out the advantages of wastewater recycling. In the case of cooling water, a substantial reduction in fresh water consumption results. With starch-containing effluent, the most important aspect of consumption can be reduced by 80-90 percent by conversion to an oil lubricating system operating via compressed air. Finally, recycling can eliminate the need for building and operating a biological clarifier.

Widmer and Widmer (749) described a completely closed circulation system for paper and board machines. The system is based on treatment of white water in flotation savealls with addition of a nontoxic slime-control additive. Experience with the system in two fourdrinier and two combined fourdrinier/cyclinder machines for production of corrugating media, coated and uncoated paperboards, and packaging papers showed it to permit machine operation with a minimum of fresh water intake and practically no effluent discharge. In addition, there were no adverse effects on product quality and production rate.

A chemical treatment system for corrugated box factory wastewaters has been developed in Japan (750). Effluents containing corrugated starch paste and flexographic printing ink wastes are combined and then flocculated and precipitated with ferric chloride, calcium or sodium hydroxide, and/or organic coagulant aids. Clarified wastewater is recycled and reused for preparation of more starch paste and a wash-up water for the flexographic printing presses. Some cost data were given, along with an outline description of the process.

Brief descriptions were given of the clearator, expunger, flexo-o-kleer, and color tamer systems for clarifying flexographic press wastewater from corrugated box plants (751). Chemicals are added to the effluent to flocculate and precipitate residual ink and other substances so that they can be separated from the water.by filtration and/or sedimentation. Reuse of press wash water in preparation of corrugating adhesive was also discussed.

A German paper mill which manufactures corrugating medium, packaging papers, and similiar coarse and low-grade paper utilizes two fourdrinier machines with completely closed water circuits with essentially no effluent during normal operations (752). The manufacturing scheme was described, including diagrams of the pulp stock and water circulation systems. Although closure of the water system has increased concentrations of solids in the white water with attendant corrosion and slime deposit problems, these difficulties are amenable to technological solutions. No adverse effect on either the quality or quantity of paper products has been noted.

Unqualified success with reuse schemes is not always achieved. Morris (753) reported that when inhouse recycle was started at a pulp and paperboard mill, it had an adverse effect on some aspects of plant operation. Recycle raised the processing water temperature which produced higher humidity, thus reducing some material service life.

Miner (754) identified factors that have limited the extent to which water reuse has been practiced in bleaching operations. The evaluation was based on a literature survey and information gained through a series of visits with mill personnel aquainted with both successes and problems associated with further reuse. Activities where water reuse practices create operating problems, such as temperature increase and corrosion, were identified, and steps taken to reduce them were noted. Where materials of construction permit, extensive or alternative bleaching water recycle practices were also identified.

Although the pulp and paper industry has made considerable progress in reducing its water consumption, much more can be achieved by using modernized methods and equipment (755). Reuse of water for washing, general cleaning, felt conditioning, wire showers, and lubrication of shaft packing boxes was discussed. Careful attention to details of mill design, including proper selection of auxiliary equipment, provisions for greater reuse of water, and machine operation, can contribute to further reductions in specific water consumption to manufacture a ton of paper.

MISCELLANEOUS INDUSTRIAL

Power plant wastewater discharge regulations require that the use of raw water be minimized and the recycling of in-plant water be maximized (756). In-plant reuse was discussed with the idea that either renovated water, raw water, or a combination of the two may be the principal plant makeup. Potential reuse and subsequent effluent effects were explored by interrelating power station water systems. It is apparent that to meet zero discharge requirements, a thorough case-by-case analysis will be necessary that will require a complete investigation of water quality, treatment, and solids separation technology.

Design criteria for power plant water systems requires that all water should be processed as required and reused insofar as practicable (757). As water is recycled in an effort to eliminate water discharges, the design must also provide flexibility so that the plant can continue to operate in the event that a part of the cycle goes out of control. Flow diagrams of the circulating water system and recycle water system at Northern States Power Company in Sherburne County, Minnesota are presented.

Jaske (758) presented an overview of water reuse in power production. He feels that water reuse will continue to play a key role in the dissapation of heat from Rankin cycle thermal effluents. Aschoff (45) discussed and illustrated various modern technologies for treatment and reuse of polluted or thermally polluted wastewaters in the power industry.

Noblet and Christman (759) examined water reuse alternatives in coal fired power plants. Five power plants were studied to identify major water problems and develop methods for treatment and reuse. Rough costs were presented for alternative reuse schemes for each water system.

A brine concentrator returns more than 95 percent of the blowdown from cooling towers at the El Paso Natural Gas Company compressor station to the towers for reuse (760). The pure water recycled to the tower dilutes the mineral content of the well-water used for makeup requirements by 25 percent. By-product salts can be recovered from the concentrated waste brine before disposal. Bromley and Gorber (761) discussed plans for maximizing recycle and reuse of water streams from a new thermal power plant to be located on the east coast of Canada.

Crutchfield and Wackenhuth (762) presented and discussed some of the problems associated with attaining zero discharge in the electric power industry. However well-intentioned this concept is, the fact remains that since matter can never be eliminated, only transformed, the proper disposal of aqueous wastes will entail some form of treatment which in itself will add to the amount to be handled.

Sengest et al. (763) provided results of a technical review of the state-of-the-art of thermal pollution control and treatment of cooling water in the steam-electric power generation industry. Current, near horizon, and future technologies utilized or anticipated to be used with closed-cycle cooling systems were assessed. The design and operation of closed-cycle cooling systems, their capital and operating costs, methods of evaluation and comparison, water treatment, environmental assessment of water and non-water impacts, permits required to build and operate these cooling systems, and benefit-cost analyses were discussed. Sufficient information to allow an understanding of the major parameters which are important to the design, licensing, and operation of closed-cycle cooling systems were provided.

Coal gasification is a relatively new industry in the United States so there are no commercial plants practicing extensive water reuse (34). Hence, there is little information available even on the quality and treatment of process wastewaters. Design of a wastewater reuse system does present problems if no comparable system has been demonstrated before. This is actually the case for a commercial coal gasification plant currently in the design stage. Wastewater reuse possibilities have been studied with emphasis on reclaiming a large quantity of process wastewater for use as boiler feed water. This is only part of the extensive effort involved in designing a zero discharge plant.

Millos (764) described design features for a water reuse system at a coal gasification plant planned for New Mexico that include reuse of a phenolic process condensate as cooling tower makeup, use of methanation water of reaction as boiler feedwater, and reuse of plant-blowdowns in the gasifier ash removal system.

The Western Electronic Company, Buffalo, New York, recirculates and reuses the water rquired for cooling hot plastic jacketing as it is extruded and formed around the outside of cable. Water consumption has been reduced by 95 percent or about 90 million gallons per year (765). The system uses a unique injection, spray-type commercial cooling tower chosen for its reliability, ease of installation and maintenance, and reduced installation and maintenance costs. The cooling tower, two pumps, and a previously unused pump comprise the recirculating system. There are two water circulating loops in the system. The recirculating system has performed successfully since its initiation in December, 1972. Costs of the system have been offset by the reduction in the need for municipal water. The system represents one way to reduce water consumption and to achieve zero discharge.

The Western Electric plant, Lee's Summit, Missouri, developed a method of treatment which rendered the plant effluent pure enough for reuse but did not result in increased dissolved solids (112, 766). An evaluation of the use of a weak base anion exchange resin indicated that a pilot plant employing six cubic feet of resin was capable of treating 2,000 gallons per day. A larger unit was constructed to handle 200,000 gpd, with provisions for scaling up to 600,000 gpd, of low-conductivity low-acidity water for reuse. A stainless steel disc filter is used to remove solids over 200 microns and an anthracite filter removes additional solids and oil. The exchange resin column neutralizes wastes and removes organics from the water. The major operating cost is for anion replacement required every seven years. This cost, however, is recovered by savings in freshwater and regenerent chemicals.

Reverse osmosis has been used at the IBM facility in Manassas, Virginia, to provide reusable water from electronics waste (767). Two-stage hollow fiber and spiral wound RO units were tested with dilute acid wastes from IBM. A hollow fiber RO system was selected in 1977 for wastewater recycling, with provisions for maintaining the fouling index below 3.0 and cleaning the permeators whenever signs of plugging or fouling occurred.

Beasley (768) described studies using reverse osmosis to treat electronic wastes. Both spiral wound and hollow fiber membranes were used. After pilot plant studies, the hollow fiber units were used to treat rinse waters for recycle.

A wastewater reclamation system, featuring reverse osmosis and a solar evaporation pond for metal wastes disposal, was installed at a California electronics plant (769). Objectives of the program were to reduce water use, improve reclaimed water quality, and reduce waste discharges which interfered with production. Costs of the system were offset by water reduction, increased product quality, and replacement of other treatment systems.

Schrantz (770) discussed the role of ultrafiltration in the technology of electrodeposition (EDP) finishing with a specific description of the closed-loop UF process of an 18,000 gallon EDP tank installed in the Equipto plant at Aurora, Illinois. Due to the closed-loop nature of the process, savings of 45 gpm of rinse water have been achieved.

Plant expansion and new processes forced the development of a water reuse scheme at a large electric machine tool plant (771). Wastewater is treated in two Imhoff tanks and a high rate trickling filter and then stored in a large pond. Water is drawn from the pond, filtered and fed back to those parts of the plant that can use it or be adapted to use it. Numerous problems were associated with perfection of this system. Approaches to the solution of these problems were presented and the results discussed.

Bhattacharyya et al. (772) investigated membrane ultrafiltration for treating TNT wastewater for in-plant reuse. Four membranes were tested. Millipore PSAL was selected as the optimum membrane due to its consistently better performance. A computer simulation was used to develop a process design for a treatment and water reuse system for nitrotoluene production. Results of this design process indicated that a tapered module system would be optimum. This system had limited concentrate recycle requirements and produced the highest solute rejection at high water recoveries.

Baker and Drury (773) presented a discussion of pilot-plant developments of water reuse technology at an ammunition plant. The treatment process requires granular media filtration and chlorination of the effluent from primary treatment. Reuse test results and projections of capital and operating costs were included. Results of the pilot plant programs and an evaluation of future potential for reuse water requirements within the plant led to preparation of a conceptual design for the treatment facilities required.

The U.S. Army's Rock Island Arsenal in Illinois has recycled all process water and discharged no effluents since 1973 (774). The fully automated system employs reverse osmosis units to treat process water prior to recycling. Annual operating costs have been reduced, and 54 million gallons of water a year have been saved.

Kelchner (775) described plans for total reuse of water at a nuclear weapons plant. Recovered water from an RO desalting unit would be used as boiler feed and in the cooling tower.

Modifications to nuclear field reprocessing facilities, process flowsheets, and equipment have permitted reuse of wastewaters and recovery and reuse of chemicals at the Atlantic Richfield Hanford Plant in south central Washington State (776). Improved process performance, reduced operating costs, and decreased waste volumes have resulted. Although these modifications were implemented for nuclear fuels reprocessing facilities, other industry may have similar opportunities in their operation.

Methods to recover or destroy complex cyanides in industrial wastewater effluents were evaluated in laboratory studies (777). Techniques tested included electrolysis, ozonation, chlorination, and heavy metal ion precipitation. It was found that ferrocyanide can be oxidized to ferricyanide in overflow photographic color process bleaches using either electrolysis or ozone and the waste bleach recirculated for reuse in the process. Dilute concentrations of ferricyanide can be destroyed using ozone or chlorine under proper conditions of temperature, pH, and catalyst addition.

Dagon (778) presented a state-of-the-art review of wastewater treatment technology available to the photographic processing industry. Current treatment methods are based on biological treatment, activated carbon adsorption, ozonation, ferro-cyanide precipitation, reverse osmosis and ion exchange. Methods of silver recovery, fixer reuse, bleach regeneration, bleach fixer reuse, and color developer regeneration are outlined.

Daignault (779) discussed pollution control in the photo processing industry through regeneration and reuse. A waste treatment system has been in operation at the PCA International color portrait processing plant in

Mathews, North Carolina, since 1972 which provides for:

1. electrolytic recovery of silver from spent fixing solutions;
2. recycling of ferricyanide bleach solutions after regeneration by ozone treatment; and
3. treatment of other wastewater by reverse osmosis; the permeate from the RO unit is reused.

In all, 20,000 gallons per day of wastewater are treated and reused.

Ciesielski (780) presented two case histories related to recycle of process waters at tall oil and turpentine chemicals production sites. Use of wastewater recycle systems has drastically reduced wastewater discharge at both locations.

Two conceptual physicochemical waste treatment systems have been proposed for animal glue plants in what is believed to be an optimum combination of appropriate unit processes (781, 782). Experimental results indicate that high reductions of common wastewater parameters could be achieved by the proposed treatment system. In addition, the purified effluent could be recycled for in-plant use.

A study of industrial laundry wastewater treatment by ultrafiltration and activated carbon adsorption has indicated that a consistantly high quality product water, potentially reusable within the laundry can be produced (783). The operation of the sprial-wound UF modules was, however, hindered by the fouling tendency of the feed system. Average module permeate flex was therefore low. This factor resulted in high capital and operating cost estimates for full-scale treatment systems.

Robertson and Pople (784) described water recycling in an aggregate plant with process water requirements of 6,100 gallons per minute. All wastewater flows are collected and treated for solids removal. Clarified water is recycled through the plant operation, accounting for about 98 percent of the plant requirements.

Ahlgren (785) conducted a thorough study of water borne wastes coming from a typical heavy equipment manufacturing operation to determine the treatment rationale necessary. After screening many possible treatment methods, a final approach was selected using settling and flotation as the primary treatment, and evaporation as the final processing step. All influent wastewater was directed to an API separator. In the RO step, recoverable product water and concentrated waste are generated. The concentrated waste is further processed through vapor compression evaporation for additional concentration of the unwanted materials and recovery of reusable water.

A study regarding wastewater reuse in the smelting industry was described by Eynon (786). This study explained the techniques required for utilizing and recycling secondary treated wastewaters for flue gas scrubbing and cooling operations in an integrated zinc-lead smelter.

Treatment of wastewater from the paint and varnish factories were examined by Freotte (787). Chemical precipitation followed by biological treatment was described. The potential for recycle was discussed. Gaefgen (788) discussed ultrafiltration of electrovarnishing wastewater. The filtrate was used as a wash liquid and recovered varnish was returned to the electrovarnishing bath.

A reverse osmosis system is being used at the Mooka plant of Kobe Steel Ltd. in Japan to treat rinse water from an electropainting line (789). The acrylic plant recovery water reuse system has reduced paint expenditure by 40 percent and overall costs by 30 percent for the plant which uses an electropainting line to apply an acrylic finish to aluminum window frames. The unit is also a closed-loop system which separates the acrylic paint and associated solvents from water so both can be reused in the process, thus eliminating the need for waste disposal to the municipal wastewater treatment system. The system should pay for itself in two years. Product water contains less than 0.3 percent of the acrylic paint ingredients.

The Modine Manufacturing Corporation plant at Clinton, Tennessee, produces aluminum air conditioning condensers with processes which generate wastewater containing zinc, aluminum, and flourides (790). In 1972, the facility modified its existing treatment system to move toward zero discharge. Plant wastewater is lime-neutralized, clarified, and fed to settling lagoons from which about 400 gpm is recycled.

Rising energy costs and stricter effluent regulations have encouraged energy-saving modifications in wastewater treatment and disposal practices of electrolytic zinc refining operations (791). Waste generation within any given process can be minimized by maximum recycling of treated water to the plant, maximum rinse without pretreatment of lightly contaminated water within the plant, and careful control of the water balance. A zinc plant designed by Kaiser engineers provides maximum recycling and minimum consumption through separation of treatment streams into nonrecyclable and recyclable effluents. Effluent discharges will be reduced to 7-10 percent of the plant's total intake of water.

Since December, 1977, Amchem Products, Inc., Ambler, Pennsylvania, has been operating a reverse osmosis and reuse system to treat wastewater from phosphating steel drums (792). The coil coating facility for a single line is capable of processing aluminum, cold-rolled steel and galvanized steel with a rinse water flow of 57,600 gpd, 300 days/year. Pretreatment consists of alkaline cleaning, zinc phosphate conversion and a final acid rinse. The RO unit was designed for a 90 percent recovery rate and a 95 percent rejection of waste stream contaminants. This process was chosen as the most practical and cost-effective alternative to conventional waste disposal methods.

A reverse osmosis process was chosen by Cummin's Engine Company, Charleston, South Carolina, for treating industrial wastes from machining and engine test operations (793). The system was chosen because it was cheaper, more efficient, and had zero discharge when compared with the standard chemical waste treatment system. The system was designed for 98 percent water recovery.

The use of activated carbon as the advanced treatment method for wastewater discharged from machinery factories was discussed by Kishi (794). Biological treatment of this wastewater is difficult since the BOD varies greatly. Activated carbon would be the most effective method of advanced treatment with the treated water suitable for reuse.

The Black and Decker plant at Hampstead, Maryland, has been a no-discharge facility since October, 1973 (795). The closed-loop water reuse system incorporates a four-stage tertiary treatment unit. The treatment plant uses a unique flocculation and filtering system and takes the effluent from the sewage plant and manufacturing process and further refines the wastes. Treated effluent from the sewage treatment plant is directed to a smaller 4-million gallon reservoir while recycled industrial cooling water and effluent from the tertiary plant is directed to a larger 10-million gallon reservoir. With the closed-loop system, the plant uses 1.2 million gallons of recycled water per day. Because of evaporation losses, 100,000 gallons per day of freshwater must be added to the plant.

The best practicable control technology currently available for the primary aluminum smelting industry is treatment of wet scrubber water and other effluents to precipitate the fluorides, to decrease the concentration of dissolved solids, and to allow recycling of the treated water (796).

Lopez and Johnson (797) reported on the use of ultrafiltration and reverse osmosis in series to treat an industrial waste stream containing process solutions, cutting fluids, rinse tank waters, cooling tower bleed, and washer waters. Ultrafiltration reduced extractable materials to levels acceptable for sewer discharge; however, the permeate was too high in organics to permit direct recycle. Additional treatment by RO allowed direct recycle into controlled systems. Behnke (798) reviewed the application of screening magnetic separators, flotation, hydrocyclone, roll media filters, reusable media filters, and precoat filters for recycling metal working fluids.

Reuse of water has been practical for several years in iron ore and coal processing plants (799). This is also true of base metal and industrial minerals processing plants. The reuse of water has occurred primarily because of economic consideration. Reuse of water is achieved by proper control of water usage within the processsing plant followed by clarification of the water by use of flocculants and a clarifying thickener. Significant savings are effected by reduced chemical consumption, conservation of heat, elimination of large tailings dams with subsequent high maintenance costs, and greater preservation of land values.

Hautala et al. (800) investigated a treatment for acidic wastewater containing iron and lead resulting from production of lead storage batteries. Presence of these metals prevents recycling of the water for production and prevents disposal to sewer systems. Powdered calcium carbonate ($CaCO_3$) added to a slurry concentration of neutralized wastewater, which was then filtered, produced an effluent with less than 0.2 ppm of iron and a lead concentration of less than 0.3 ppm. Further filtration through a bed of redwood bark produced an effluent suitable for recycling or disposal to a sanitary sewer system.

All wastewater from the Globe Union Inc. lead acid battery manufacturing plant in Canby, Oregon, is clarified, filtered, and recycled (801). Suspended solids in the waste stream, i.e. lead oxides, are reused. About 280 liters per minute of wastewater are reused and 280 pounds per hour of solids recovered. Capital and operating costs are given.

SECTION 4

RECLAMATION PROCESSES FOR INDUSTRIAL REUSE OF WASTEWATERS

There is considerable interest among United States industries in developing methods for consolidating and reducing waste loads within their operations so that they can comply with effluent standards that will be imposed as a result of the FWPCA Amendments of 1972 (143). As a part of these efforts, an attempt is being made by industries to reduce freshwater consumption so that both the cost required to produce their product and the waste volumes they generate in their operations can be minimized.

The quality of water required for various industrial uses often dictates the most desirable form of reclamation and reuse. For example, water for many industrial uses need not be of as high a quality as that used for human consumption. Therefore, it is often possible to reuse treated wastewaters for industrial purposes. In the majority of cases involving reuse, it is necessary to provide some form of treatment (5). The extent of pretreatment will depend on the concentration and type of pollutants and the water quality requirements.

A great deal of concern has been expressed for the future development of wastewater treatment systems (43). The primary concern is for finding means of reusing treated wastewater instead of merely disposing of it. This involves the introduction of systems which can provide water of the required quality. Any system or method must be cost effective.

Industrial water can be used on a once through basis, or as is becoming more frequently the case, on a multiple use or a reuse-recycle basis (802). The trend is to increase the reuse ratio to a point where minimal or zero discharge of water is achieved. This requires new chemical and mechanical methods for water treatment to remove salinity, hardness, alkalinity, suspended solids, and organic matter.

Steps in establishing a zero-discharge strategy are: 1) inventorying water consumption item by item and listing positive means to be adopted to limit consumption to minimum levels required by each process stage; 2) defining qualities of water required; and 3) establishing treatment levels for recycle of water (803).

Interest in greater reuse of treated wastewaters has focused attention on the need for critical evaluation of the effectiveness of water and wastewater treatment processes (804). Their capability for removing undesirable constituents from wastewater must be known in order to correlate the degree of treatment and level of quality to a particular reuse application.

Reclamation and reuse of wastewater has been inhibited by: confusion concerning objectives of water reuse, need for relating treatment effort to the use, guidelines regarding effluent discharge, and serious consideration of energy conservation versus water reuse (15).

There are many possible routes to complete water treatment, and for each individual case a very careful study should be made to select processes that will give the desired objective with minimum capital investment and operating costs (805). An essential part of a complete water reuse program is to first employ all known techniques for minimizing wastewater from manufacturing operations (19).

There are two basic methods by which recirculation systems are designed and operated (21). Recirculation can be incorporated on each separate process, or all process waters can be combined, treated to the extent necessary, and used as intake water for all processes. The choice usually depends upon the water use system prior to design of the recirculating system. Most new plants use the first system while most older plants utilize the second approach.

Advanced wastewater treatment processes may be applied to wastewater in treatment systems for which the effluent water quality improves through each additional process in the treatment sequence (806). Since cost of treatment increases with each additional process in the treatment sequence, the user should select the minimum water quality required for the reuse purpose and thus minimize size of the treatment plant and cost of treatment.

The assumption that improvements in quality of receiving water is related to increased sophistication of the treatment process must be replaced by an effort to match treatment efforts to reuse objectives (15). A treatment system designed to meet stream quality requirements can not always be effectively used to meet reclaimed supply requirements (9). Weber et al. (807) noted that conventional "secondary" biological waste treatment processes are often inadequate to provide the effluent quality needed for water reuse purposes.

For many years it has been recognized that conventional primary plus secondary biological treatment is not able to produce effluents of sufficiently high quality to be suitable for direct reuse (808). This is especially true when the conventional method is applied to treatment of certain industrial wastes which are either relatively refractory or biotoxic. Considerable research interest has been focused on new and advanced waste treat technologies with the hope that these new technologies will provide sufficient degrees of treatment so that treated effluents can be reused directly. Huang, et al. summarized results of a research study designed to investigate the effectiveness of carbon adsorption for the treatment of three selected industrial wastes: a refinery wastes, a high-strength acidic chemical waste, and a pharmaceutical waste.

There are many possible wastewater reclamation processes and schemes, of which one or more in combination can be used to solve almost any special waste treatment problem. Sawyer (60) reviewed the status of wastewater treatment technology and evaluated various chemical treatment methods and water recycling schemes. Both in-plant recycling systems for various industries and municipal wastewater reclamation systems for industrial and general use were covered. Cost data for various treatment processes were indicated.

Water reuse is a recognized option for augumenting water supplies to provide for expanded water needs. A methodology has been developed by Bishop et al. (809) examining optimal strategies for water reuse within the context of the total water resources system, including both the provision of water supplies for various uses and management of wastewaters. The optimizing objective of the formulated model is to minimize the cost of meeting water supply requirements and of wastewater treatment to satisfy effluent requirements.

Mace (116) discussed a procedure for conducting an in-plant study to determine feasible recycling schemes. Finelt and Crump (810) directed interest toward development of industrial plant water recycle policies. These efforts could reduce water cost and effluent discharge. Several systems utilized in water reuse operations were discussed in terms of cost, procedure, and efficiency.

Norman and Busch (811) discussed applications of biological waste treatment technology to renovation of wastewater for reuse. Principle topics were the application of biological processes for water reuse and engineering decisions leading to the optimum selection of process units.

Various wastewater treatment sequences were evaluated by Petrasek and Rice (812) as part of a research program for developing water reuse systems. Treatment sequences evaluated consisted of the following unit processes operating in series, with the most significant difference being the type of chemical treatment utilized in the sequence: biological treatment with completely mixed activated sludge; chemical coagulation, flocculation, and clarification; multi-media filtration; and activated carbon adsorption.

Ricci (813) reviewed laboratory and pilot-scale developments in water reuse systems. A pilot-scale system that renovates organic chemical-laden wastewaters for reuse in manufacturing operations was described. The system combines activated sludge treatment, physical/chemical treatment, reverse osmosis, and primary and secondary ion exchange. Another pilot unit has demonstrated the effectiveness of ultrafiltration for concentrating dilute latex wastewaters for reuse.

Rickles (88) described techniques applicable to treatment of industrial wastewater for reuse purposes in chemical process plants and discussed several examples. Shuval (814) reported on recent advances in technology conducive to achieving greater efficiency in water reuse. Linstedt and Bennett (815) evaluated advanced waste treatment technology for production of industrial grade water. Several major reclamation and reuse systems for steel, pulp and paper, and petroleum industries have been described (816).

Rose (817) offered a brief description of various unit processes either utilized in existing advanced waste treatment plants or being considered for plants in the study or design phase. Factors entering into design of process equipment for advanced waste treatment were analyzed. Pollution control by itself is frequently insufficient to restore wastewater to a point where it will be suitable for reuse. Further treatment may be necessary to actually renovate or renew wastewaters so that they can be available for reuse. Renovation of wastewater for reuse requires separation from the liquid phase of several distinct types of contaminants: suspended solids, colloidal solids, dissolved organic solids, and dissolved inorganic solids. Removal of each type of material requires a different unit process. Selection of a particular treatment process therefore is a function of the type and composition of water to be treated in the process and quality required in the product water.

Hospodarec and Thomason (33) discussed schemes showing various methods of recovering effluent streams for reuse. They noted that streams high in dissolved solids do not lend themselves to reuse without extensive processing.

Marynowski et al. (818) described three promising wastewater schemes which may have favorable application in industrial wastewater renovation. The three processes analyzed were:

1. ion exchange treatment of ammonium nitrate plant waste;
2. evaporation of steel mill waste ammoniacal liquor; and
3. treatment of power plant stuck scrubber blowdown by electrodialysis and evaporation.

Estimates of capital and operating costs were prepared for all three illustrative applications.

Bishop (806) provided a description of two basic advanced treatment systems and a brief review of three other systems which represent combinations of processes from the two basic systems. A summary of the average or typical water qualities of the intermediate and final effluents from each of the five treatment systems was given.

Bayley and Waggott (819) described several recent developments in water reclamation processes. Filtration, ultrafiltration, adsorption on granular activated carbon, coagulation, ion exchange, and reverse osmosis were included.

Leitner and Ahlgren (820) reviewed various conventional and advanced processes available to industry for solution of their problems of water supply and reclamation, waste disposal, and recovery of certain valuable materials. Electrodialysis, reverse osmosis, and evaporation were the principal techniques discussed. Cost figures were also provided.

Kelsey (821) discussed reuse of water from the standpoint of materials recovery. Methods of treatment included reverse osmosis, ultrafiltration, electrodialysis, polishing filters, adsorption, and ozonation.

Goddard (822) compared operating principles, application, and capital and operating costs of ion exchange, electrodialysis, and reverse osmosis. The choice among these three treatment processes is dependent on numerous technical and economical considerations, including the desired treated water quality. These factors were discussed in some detail.

Desalination processes such as reverse osmosis, evaporation, ultrafiltration, and others have been studied for their potential as water recovery methods (823). Demonstrations have shown the feasibility of recovering usable water from a wide variety of effluents. Pilot-scale demonstration systems have been constructed and operated, and data have been gathered relative to economics of water recovery and product water quality. In addition to water recovery, these processes concentrate unwanted solid materials for ultimate disposal.

Evans (824) discussed the question of the effect of mineralization of wastewaters on reuse, and concluded that mineral content is the basic characteristic which determines the number of cycles that reclaimed water can be used.

Spiewak (825) conducted a review of the major aspects of desalting technology and reviewed the more promising methods. These included electrodialysis, reverse osmosis, dynamic membrane hyperfiltration, and distillation. Nearly all the processes lead to a product water of greater purity than that of most natural waters used for municipal supplies. However, these processes also produce a resultant concentrate which is very difficult to dispose of. Cost estimates were formulated for various systems alternating between complete recycle and no recycle.

Kalinske (826) deals with eventual disposal of solid and liquid pollutants and residues that are removed by various treatment processes. As in wastewater treatment, ultimate disposal of solids or liquid sidestreams generated by water reuse treatment must be considered an integral part of any process, both technically and economically. Costs associated with processing and disposal of the residues must be considered part of the treatment cost.

Preparation of wastes and polluted waters for reuse requires treatment for removal of inorganic and organic contaminants released to the water in its prior use (827). Conventional water and waste treatment techniques are inadequate and uneconomical for preparing poor quality waters for reuse. Since water purification basically involves solute-solvent separation, reverse osmosis membrane technology offers considerable promise as a wastewater treatment techniques; however, new and improved membranes are very much needed to improve the economics of RO technology for water reuse applications.

According to Channabasappa (27), the RO process offers an excellent tool for industry to meet the challenge of pollution control in the future. He noted, however, that while present RO membranes and equipment are suitable for certain wastes, new families of membranes and equipment designs are needed to improve the economics of by-product recovery.

A preliminary survey of 18 industries was made to determine the economic potential of by-products recovery (27). The following six industries were found to offer the most potential: cheese, pulp and paper, organic chemicals, nuclear power, iron and steel, and metal plating. Membrane processes appear to be most suited for by-product recovery with reverse osmosis better suited than electrodialysis. Besides by-product recovery, an important economic incentive in using RO for industrial waste treatment is recovery of water for plant reuse.

In order to employ a closed-cycle system, methods for removing dissolved solids must be incorporated within the treatment cycle (5). Studies indicate that the reverse osmosis process has the best chance for serving this purpose, and there are stong indications that it may be used to replace secondary and tertiary procedures.

Nusbaum and Kremer (828) discussed reclamation of used water by reverse osmosis. Reverse osmosis can remove purified water from a mixed stream containing organic and inorganic pollutants leaving a concentrated stream of these pollutants amenable to recovery, if justified, or to facilitate disposal.

Cruever (40) summarized the status of development of reverse osmosis processing for reuse of acid mine drainage, municipal sewage effluents and some industrial streams. Current capital and operating costs were presented and future improvements outlined. Technical feasibility of spiral wound RO processing for use of many industrial and municipal waste streams has been demonstrated. Limitations to the application of RO to water, wastewater, and other aqueous solutions were listed.

Witmer (829) discussed the potential of low pressure RO systems in water reuse applications. In order for low pressure RO to become a viable process within the wastewater reuse leg, costs must be pinned down for the overall process which are, of course, inclusive of pretreatment and brine disposal costs.

Bregman (830) initiated studies in which reverse osmosis was employed for reclaming various types of wastewaters. These studies were discussed in detail. Because of difficulties encountered, use of several pretreatment techniques were necessitated. It was concluded that there was an obvious need for tailor-made membranes for the retention or passage of specific materials, that problems of organic fouling must be overcome, and that membrane compaction difficulties must be remedied.

Reverse osmosis may be regarded as a technique of separating components of waste streams to accomplish one or more of the following: 1) reclamation of water for reuse; 2) concentration of the constituents of reuse for convenient disposal; or 3) abatement of pollution. Golomb and Besik (831) discussed five basic reverse osmosis designs and assessed the feasibility of employing reverse osmosis for treatment of various industrial wastewaters.

Beder and Gillespie (832) delineated in detail both the design and operational variables for the reverse osmosis process when employed specifically for reclamation of pulp mill effluents. The process compared favorably with massive lime and activated carbon treatment. The authors concluded that reverse osmosis would fit best after primary treatment but before activated carbon treatment when reclaiming wastewater for reuse.

Reverse osmosis is finding an increased number of applications to reduce the volume of industrial wastewater (30). In addition to the standard application where the waste is processed so that a portion can be reused, incorporating reverse osmosis into the process frequently reduces the volume of waste which is produced. Kremen (833) reviewed the concept of reverse osmosis and briefly discussed its effectiveness in purifying different types of waters and the economics (capital and operating costs) of reverse osmosis treatment.

Koyima (834) and Koyima and Tatsumi (835) discussed reverse osmosis treatment of industrial wastewater for production of reusable water. Leitner (836) reviewed the applicability of reverse osmosis to industrial renovation and reuse systems. Application was most advantageous for plating waste, food processing, and treatment of cooling tower water.

Ironside and Sourirajan (837) discussed the use of reverse osmosis as a means for reclamation of wastewaters, and presented results of laboratory investigations with cellulose acetate membranes. Gregor (838) discussed the effects of hydrogen-bonding, pH of influent water, porosity, and contamination of organic matter on cellulose acetate membranes used in reverse osmosis systems for water reclamation. It would appear that only the product water from the moderate and highly selective membrane modules would be satisfactory.

Reverse osmosis is not in itself without short comings (366). Major obstacles limiting reverse osmosis today are membrane fouling and high cost. High costs can be alleviated somewhat when by-products of value can be recovered with use of the membrane process. Membrane fouling can be reduced by using an appropriate pretreatment process to remove fouling constituents prior to their introduction into the reverse osmosis unit.

Murkes (839) discussed problems still to be resolved in development of membrane systems. Major problems identified were membrane fouling and secondary membrane formation. In a reverse osmosis water reuse or recycle process that achieves partial demineralization of the waste stream to control the level of dissolved solids, precipitation of sparingly soluble calcium compounds can produce serious operational problems when not closely controlled (840).

Shimozato et al. (841) reported on experiments dealing with membrane scale prevention during wastewater treatment with reverse osmosis. A combined chemical and ball cleaning system was operated continuously for 1500 hours and demonstrated both effectiveness and reliability. Application of reverse osmosis to closed-system wastewater treatment is illustrated for the electronics industry. The use of electrodialysis and evaporation in closed-system treatment is also discussed.

Reverse osmosis can provide for recycling of effluents when combined with filtration and ion exchange (842). Principles, applications and limitations of reverse osmosis was the subject of a two-day seminar attended by representatives of various industries. Reverse osmosis must be matched to local conditions such as turbidity, water hardness and colloid levels.

Kaup (843) compared two water purification processes that can be used to control mine drainage pollution and still produce a potable water with a minimum of disposal problems. Results of the DESAL ion exchange process are presented and compared to published reverse osmosis work.

Newman (844) discussed application of a novel fluidized moving bed ion exchange resin system to several waste recycle applications. Data are presented from a commercial installation in operation on recycled scrubber wastewater, and hypothetical cases are presented with tabulated data for recycling chromates from cooling water blowdown. He concluded that ion-exchange can be a major factor as a reuse tool.

Ion exchange has been used in industry for many years in recovery of valuable substances from industrial liquids and purification of these liquids for their reuse (845). The economic limitation of this process comes from the expensive regenerant that must be used in order to obtain the original ion exchange resin again. Difficulties arise because, in many cases, substances to be removed are in low concentrations. The AVCO continuous moving bed process is described. The ion exchange, regeneration and wash operations occur simultaneously in the same column.

Mace (846) reported that use of granular media filtration for removing suspended solids from wastewaters which are intended for reuse has recently increased. Granular filters are also the only time-tested unit operation available for filtering volumes of wastewater experienced in industrial waste treatment plants. The various types of granular filters and their performance and application in reuse situations were discussed. Types of granular filter configurations available include: vertical gravity, deep media vertical gravity or pressure, horizontal, concrete gravity, and upflow gravity or pressure types.

Processing industrial wastes by reverse osmosis or ultrafiltration can bring about process economics by recovery of valuable materials dissolved in the waste stream, by recovery of high quality water for reuse, and by concentration of pollutants for disposal (847).

Bregman (830) presented results of studies with both reverse osmosis and electrodialysis which show that it is technically feasible to convert sewage to potable quality. Costs and results of RO treatment on a variety of wastewaters are presented. Problems encountered are listed.

The ultrafiltration process may play a key role in most industrial water and wastewater treatment systems as environmental regulations get tougher (848). Descriptions of three types of membranes used in ultrafiltration systems are given. Generalizations regarding pricing are considered.

Membrane ultrafiltration with non-cellulosic membranes is a promising technique for the removal of various organic compounds present in aqueous solutions, particularly for waste treatment systems designed for in-plant water reuse (849). The process has been successfully used as an effective technique for treatment of a large number of industrial wastes.

Use of ion exchange and electrodialysis systems to treat various industrial process wastes for recycle was described by Fisher and McGarvey (496) and Westbrook and Wirth (850). Electrodialysis applications were discussed by Birkett (851). Design and operation of the process may require more skill and care than that of other systems. It does not appear to have general utility as a waste treatment tool. Its most likely areas of application are recycle and reuse of recovered products in industrial wastes.

Korngold et al. (852) conducted pilot plant studies to examine application of electrodialysis to a variety of industrial wastewater effluents with low salt concentrations and few membrane fouling components. The technical and economic feasibility of electrodialysis treatment was considered for the following industrial wastewaters: chemical copper plating, chemical plating, electro-plating, phosphate plating, and sulfuric acid pickling.

Water reuse is possible only after applying some kind of treatment of water that has been already used (853). Distillation promises to be among the most important treatment units for water reuse systems as technical and economic aspects are improved, and as more experience in this service is gained. The distilled vapor is condensed for recycling to process or other uses while the contained salts are concentrated to the solid form for disposal. Through the distillation process is old and well established, and technically ready for application to waste streams, certain problems still hinder its widespread usage. These are primarily related to costs.

To be suitable for conventional boiler make, effluents from treatment processes must go through pretreatment for removal of troublesome constituents (854). A typical flow diagram of makeup water treatment was presented, including a cationic exchanger, degasifier, anion exchanger, and a mixed bed of cation and anion exchange material. Evaporators are still a significant factor in feed water treatment. Multi-stage flash evaporators produce excellent feed water. Also presented was a short discussion on condensate treatment.

An evaporative process has been developed for reclaiming industrial wastewater (802). The process has been demonstrated through operation of pilot and full-scale facilities on a variety of feed waters. The system consists of a two-stage evaporator with associated deaerator, feed and product pumps, recirculation pumps, holding tanks, heat exchangers, mixers, compressors and automatic controls. The system is configured to permit operating of either stage by itself or both stages together.

Stepakoff and Siegelman (2) gave a summary of the eutectic freezing process along with a brief review of the results of bench scale testing of process components and feasibility studies. The freezing process is an extension of desalination technology and has broad application in the recovery of water from wastes having a high content of organic and inorganic dissolved solids (855). Freezing effects all the dissolved contaminants in the effluent. For treatment of concentrated wastewaters, the system may have economic advantages over chemical destruction.

Emmermann et al. (13), Iammatino (856), and Ziering et al. (857) described the Avco crystalex freeze crystallization process for concentrating industrial wastes and producing reusable water. Its application to a variety of industrial wastes was summarized. The process is based on the fact that ice crystallized from an aqueous solution contains pure water, with all impurities remaining behind in the concentrated solution. The ice crystals can then be efficiently washed free of adhering mother liquid to potable water standards or below. The process uses a secondary refrigerant, Freon 114, which is inflammable, nontoxic, and practically immiscible with any aqueous waste.

The crystalex process ck produce a reuable product stream with as little as 30 ppm total dissolved solids with 99.9 percent contaminant removal, as demonstrated by large scale laboratory tests. These tests also indicate that all dissolved contaminants are reduced in the same ratio, regardless of their relative initial concentrations.

The AVCO concentrex process is an extention of the crystallex process (13). It is a two-stage arrangement which is applied when the final freezing point depression exceeds 5° - 10°F. In this case, concentrate for the first stage is feed for the second stage. Need for the second stage depends on the highly varying freezing point depression for different aqueous solutions. Flow schematics of both the crystalex and concentrex systems were presented.

Sephton (858) discussed the effectiveness of a novel evaporation method which reduces energy and capital cost requirements for the renovation/recycle of industrial wastewaters. Interface enhancement depends on foamy two-phase vapor/liquid flow induced during the evaporation of a liquid flowing over a heat transfer surface. This flow mode substantially increases the evaporation rate of the liquid, after adding a surfactant.

Equipment for the cooling of industrial wastewaters to be recycled has been described (859). The atmospheric cooler operating in a closed cycle, and providing direct contact between the wastewater to be cooled and the air, has a water consumption amounting to only two percent of that of an open-cycle cooler.

Increasing demand for clean water coupled with the rising costs of treating wastewater for discharge is prompting industry and government to examine new avenues of water conservation (860). One approach is reuse of treated plant effluents. There are several technically sound and economically acceptable unit operations which can prepare a waste stream for further use. One of these is adsorption using granular activated carbon. If employed properly, effluent from the treatment system employing granular activated carbon will be clean of suspended solids and relatively free of organic materials which may effect additional unit operations used to prepare the water for reuse. Advantages offered by an adsorption process, such as flexibility and dependability, together with economic considerations and its history of proven performance makes it a process that should be seriously considered when planning a water reuse program.

Rizzo (861) reported that granular activated carbon adsorption is a unit process which treats wastewater to a quality suitable for reuse. Chow (862) investigated activated carbon adsorption as a tertiary treatment in wastewater treatment and reuse systems. The costs and efficiency of water reclamation by activated carbon were summarized by Cooper and Hager (863), and processing design parameters were tabulated for optimizing engineering decisions in reuse.

Through a simple physico-chemical treatment process, dyes of all types can be removed successfully from water along with elimination of remaining substances (864). The purification effect can be controlled and continued until drinking water quality is reached. The process is insensitive to disinfectants, temperature, and intermittent discharge. There is no feed-in phase, and the water may be recirculated.

Helfgott (865) presented a process flowsheet suggesting a graviational electrodialysis (GED) system for water renovation on reuse. GED is an electrokinetic technique that fractionates organics by migration in an electric field. Analytical and process classifications were shown for several industrial wastewaters.

A precipitator has been manufactured by Precipitator, Inc., of Santa Fe Springs, California, for the reclamation of water from waste streams (866). The Lindman Precipitator is a physical and chemical wastewater treatment system using sulfur dioxide, iron, and lime in a continuous-flow process. Workings of the system are described along with test results and operational data. Operating costs for the system are estimated.

A process has been provided by Haase, et al. (867) for the purification of industrial effluents, in particular the decolorization of wastewaters occurring in the textile, paper, and leather industries and in the manufacture of flourescent brightness and dyes. The process consists of bringing the effluents into contact with an adsorption material that contains a carrier which has been pretreated with a precipitate of a basic, nitrogeneous polymeric compound with an activated clay mineral. On account of the broad applicability of the adsorption material, it is possible to meet the ever present demand for saving fresh water by a partial to complete recirculation of residual or waste liquors.

A patent has been issued to Phillips Petroleum Company, Bartlesville, Oklahoma, for a process to purify aqueous waste streams containing organic material impurities (868). Contaminated streams are mixed with an oxygen-containing gas and a copper manganite catalyst under liquid-phase oxidation conditions at a temperature of 350°F. Organic materials are converted to relatively innocuous forms, and the stream can be safely discarded or reused.

A process has been patented for the effective flocculation and coagulation of an epithalohydrin with a specific family of alkylene polyamine, the polymerization being carried out under certain conditions and utilizing specific concentrations of the respective ingredients (869). The process will remove fines and fibers from the aqueous systems of certain industries to permit water conservation and reuse and/or to insure that the water is acceptable for discharge.

Greiser (870) classified wastewaters and projected the potential for recycling water and all waste constituents for useful purposes. A proposed system provided for solids/liquid separation with subsequent use of water as a feed for stream generating plants.

Golov and Egorov (871) discussed a treatment system less costly than discharge employing flotation to produce water for recycling. Read and Manser (872) surveyed methods used to remove organics by flotation processes and produce reusable process water.

A demineralization system combined with a system using a relatively nonvolatile fluidizing liquid has been patented (873). Dehydration by heat evaporation and condensation provides a condensate water effluent and a slurry. A portion of the condensate water is returned for industrial use.

Thorne (874) discussed an electrolytic process for the continuous recovery of metal powders and the production of potentially recycleable water. Sphere, Inc., Bedford, N.Y., has been assigned a patent for a treatment process which comprises passing an electric current, preferably off peak current, through a liquid waste to convert the water content of water vapor, thereby sterilizing the total body of the waste (875). This is followed by utilization of the vapor and its sensible and latent heat for recycle and reuse. When applied to systems which are large users of power and water and which discharge large quantities of liquid wastes, the process of this invention will result in both environmental and economic advantages.

A patent has been issued for a highly efficient process for separation of oil from water in wastewater treatment (876). Paraffinic hydrocarbons with a specific gravity of less than 0.8 are added as extractive solvents. This mixture is then stirred and allowed to stand; the floating oil-containing scum is then removed to eliminate fats and oils from the wastewater. The resulting treated water may be reused as process water in the plant or discharged.

The thermopure process, developed at laboratories of ALCOA, uses waste heat to purify industrial and sewage wastewaters (877). Waste heat is used to concentrate waste products for reuse or simplified disposal and also produces deionized quality water that can be reused. A process description is given. The process employs conventional materials and established engineering technology and is operated with low-pressure steam generated preferably by waste heat from various sources.

La Sasso et al. (878) discussed the benefit of polymers for increased efficiency of liquid/solid separation. The application of polymers falls into three broad categories:

1. recovery of liquid stream where the desired product is dissolved in water;
2. recovery of a solid product from a liquid stream; and
3. recovery of water for reuse.

Higher recoveries, greater throughput and lower energy costs in subsequent drying steps have led to acceptance of polymers in these areas. In recycle systems, the fact that polymers do not add substantial amounts of soluable ions to the system is important.

The optimum system for any industrial plant will be unique to some extent; seldom can a system simply be copied from another installation (8). There are however, sufficient criteria and operating data available from existing installations to design any such system, without exceeding a "state-of-the-art." Such methods should be receiving careful consideration as the most practical long-term solution to industrial pollution abatement.

SECTION 5

ECONOMICS OF WATER REUSE AND RECYCLE

Water reuse is becoming an increasingly attractive solution to industry (13). New, stricter pollution control standards require large expenditures to clean industrial waste streams. In many cases, only a small additional cost would bring these same streams to reusable water quality. In addition, the cost of providing fresh water from local supplies is increasing. Many industrial streams are spent wastewaters; it is often possible to recover by-products of value from the waste. All of these factors combine to make water reuse an increasingly attractive economic alternative.

Wastewater reuse is a resource conservation measure and a method of pollution abatement (879). By-product recovery and utilization techniques can reduce the net cost of waste treatment and hopefully will become less expensive than disposal. Recycled water is valuable because of intake water supply shortages, increasing water supply and treatment costs, and rising municipal sewage charges. The recovery of usable water and thermal energy are the main techniques of reducing overall waste treatment costs.

It cannot be overemphasized that the goal of complete water reuse is the only economical way to achieve minimal pollution of our fresh-water supplies (826); moreover, reuse will be the only economical method by which an increase by several times the amount of water available for industrial and domestic use can be achieved.

The strongest arguments for the reuse of water in industry are to be found in production costs (880). Water is one of industries' raw materials, and it costs money to buy it, to process it, and to dispose of it as effluent; consequently, water use and effluent disposal must be considered technically and economically as integral parts of production costs.

The concepts of water reclamation versus its antithesis, that wastewater is fit only for disposal, were discussed by Suhr (16). Probably the most important aspect of wastewater reclamation is pollution abatement. Furthermore, estimated costs of recycling may be less than the cost of merely treating wastewater for disposal. Economic advantages that may be gained by recycling were illustrated.

Costs play an important part in determining the practicality of recirculation systems or any other pollution abatement system (21). However, costs to the system uses alone do not necessarily determine the economic desirability of any such measures. Costs must be compared to the overall benefits to be derived in evaluating the economics of pollution control. Costs must be determined in each specific case and will vary widely among industries and among plants within particular industries. Costs vary primarily because of the water volume to be handled, water quality required for the process, degree to which recirculation is previously utilized, extent of the combination of process and cooling waters, and local conditions which affect the difficulty of construction.

Struzk (881) reviewed reuse trends for a variety of industries for the period of 1964-68 and found that economics played a role in a shift in favor of water reuse. Nernerow and Canotis (882) analyzed the economics of industrial waste treatment and observed that reuse should be considered in the cost benefit analysis. De Rooy (883) reported that price has a great effect on demand for industrial water supplies and that there is a great economic incentive for application of reuse in this area.

In order to promote industrial implementation of in-plant water management programs, Irvine and Davis (884) presented the concept of water conservation and reuse. Cost analyses were presented that point out the economic benefits of conservation and reuse. In addition, procedures were described that increase the efficiency of biological waste treatment facilities. Segregation of waste streams was stressed. Also, with the implementation of conservation and reuse programs, the cost of waste treatment becomes part of the production scheme.

It is conceptually possible to process any quality water for any use with existing technology with the major constraints of operation and control (18). The concept of total plant water management relying upon conservation, reclamation and reuse can, if properly conceived and implemented, provide the most cost-effective means of solving pollution problems.

Stephan and Weinberger (885) noted that wastewater renovation for reuse is technically feasible and that costs are related to the degree of treatment required to meet a particular reuse purpose. Billings (585) defined the economic limits for extending water resources by water reuse and raised the technical problems involved and put them in perspective.

Rambow (103) analyzed and tabulated the cost of industrial wastewater reclamation. In some cases reclamation may be the most desirable solution economically and otherwise, even where water is abundant. In many cases, reclaimed water is of higher quality than untreated water. Tabulated cost data include capital costs of tertiary treatment plants, yearly operating costs of tertiary treatment, basic system costs, basic system costs less secondary treatment costs, electrodialysis costs, and reverse osmosis costs.

For many industries reuse of water may significantly decrease total water and wastewater treatment costs (886). However, in other instances the cost of process modification required to implement water reuse practices might more than offset saving in water costs. The incentive to reuse water will be determined by the net savings realized. In order to illustrate savings which might be achieved, examples were developed for several of the major industries in the Cleveland - Akron, Ohio area.

When disposing of wastewater causes loss of valuable products, value of water supplies is high, effluents are strictly regulated, pollution drainage is excessive, or if effluent quality must be higher than the quality of available raw water, it is cheaper to reuse water then dispose of it (887). Costs of disposal, treatment conveyance, and reuse processing are tabulated and shown graphically to permit comparison of costs of alternatives.

Dahlstrom, et al. (888) reported that reuse of treated wastewater to meet regulatory requirements is often economical. By-product recoveries may represent substantial credit to the overall costs. Two examples of water reuse and reclamation are given.

System costs for water renovation and reuse were reviewed in terms of 1974 dollars by Middleton (889). Unit operations were identified with respect to performance, applications, and costs.

Expensive local water costs and high sewer costs add incentives to the use of recycle (158). Recycle of treated effluent reduces the raw water requirement and the volume subject to sewer charges; therefore, savings are made at both ends.

Long-range economics foreseen in total water reuse systems, such as lower water-use costs, no discharge surcharge costs, and potential savings in by-product and/or product recovery, are certainly maximized at a manufacturing facility when the end result is maximum water conservation at maximum production with no water pollution (9).

Analysis of water use, reuse, recycle, and economics must consider the problem of ultimate disposal (5). The total mass of solids will not be decreased through conventional reuse and recycle practices. Consequently, concentrated waste streams must be disposed of in some suitable manner and this charge must logically be added to the cost of water management.

The product of waste must be considered as an integral part of the manufacturing process, and the cost of treating industrial wastes must be charged against the product (39). Product recovery processes can frequently reduce the cost of treatment and accomplish various degrees of pollution abatement at little or no expense.

Choijnacki and Krzyzanowski (890) compared economic aspects of water purification and waste treatment with closed-cycle processing for various industries. Partridge and Paulson (36) considered economic reuse of water in a closed system. Morris (35) provided a summary of technical capabilities and economic considerations in wastewater renovation.

Bramer (8) presented results and conclusions from a study on costs of implementing minimum and zero discharge requirements for the manufacturing and electric power industries. Assumed technology was maximum in-plant recirculation and reuse, concentration of the recirculation blowdown by evaporation, and final residual disposal by the applicable least-cost method among incineration, deep-well disposal, solar evaporation, and ocean disposal.

Clayton (891 provided a detailed description of the Windhock wastewater reclamation plant. Special attention is given to the economics of the operation. All aspects contributing to the total operating costs are analyzed and tabulated.

Anderson and Marks (892) approached economic considerations from the need to integrate the treatment and reuse system with other process requirements. The analysis considered the effect of total fixed investment and operating costs to the real cost of water to the user. Hernandez (893) analyzed the energy used for advanced wastewater treatment. Costs were divided into three components: plant operations, support services, and indirect uses. Energy used in the operation of the treatment process was found to be minimal when compared to support services and indirect services. Parker (894) discussed the economic impact on industry of the zero-discharge concept. Costs, technology and economic analysis will require considerable effort before implementation. Anderson (895) analyzed technological and economic factors of importance when considering industrial water reuse systems. A general assessment method was presented.

Costs of establishing water pollution control systems including water recycling have been presented (816). Reuse of water could actually cut wastewater treatment costs, and, in some cases marketable by-products might be produced.

Engineering techniques for improving water economics to reduce water consumption and contamination were discussed by Hnetkowsky (896). Garrison and Miele (897) presented cost estimates for treatment processes necessary for the various modes of reuse.

Anand, et al. (898) conducted a study to determine the cost of wastewater treatment as a function of plant size, waste characteristics and degree of treatment. The analysis was based on flow sheet combinations of three plant sizes, two wastewater strengths, and three levels of effluent quality. Cost analysis included construction costs, operational costs, equipment costs, and chemical costs. The processes were given, as were costs for dewatering and disposal methods.

Smith (899) examined the economic feasibility of using renovated wastewater to supplement raw water sources. Operating, maintenance, and capital costs are estimated for various wastewater renovation processes which might supply 1, 10, and 100 mgd requirements. Cost of such treatment is dependent on the uses to which the water will be applied. In general, wastewater renovation may represent higher costs than water from normal sources. Wastewater renovations however, compares favorable with development of new sources of raw water.

Determining the amount of water to be reclaimed is an economic based decision, providing the technology is available (646). Each industry has its own individual needs and problems, but all such water mangement problems have these general considerations: production process water requirements, cost and quality of fresh water, cost of effluent treatment, and cost and quality of reclaimed water.

A systematic approach for analyzing the economics of wastewater disposal versus reuse is presented by Mace (900). The approach consists of four major steps: 1) a detailed analysis of the effluent; 2) a determination of the effect of recycle water on product quality; 3) a survey of waste treatment operations available; and 4) a total economic analysis. Cost data for a hypothetical problem involving the following three alternatives are presented: 1) purchase and sewer disposal of 100 percent of the water; 2) recycle of 50 percent and sewer disposal of 50 percent of the wastewater; and 3) recycle of 90 percent and river discharge of 10 percent of the wastewater. Figures cited are intended only to demonstrate results that can be derived from a well-planned program of industrial plant design.

McIlhenny (901) reviewed the treatment and reuse of industrial wastewaters in order to increase industrial water supplies, with particular reference to cost and economics. Dahlstrom (902) discussed economics of water reuse as the key to handling water and wastes at maximum profitability. Bridgewater (903) presented a series of articles on methods available for estimating costs and evaluating proposals for both effluent treatment plants and waste recovery and recycling possibilities. Dukstein and Kisiel (904) presented a discussion of a cost-effectiveness approach for comparison.

The social, economical, and technical practicality of wastewater reclamation was investigated for domestic, agricultural, irrigational, recreational, and industrial reuse (54). A cost-benefit model was presented that can determine the overall socio-economic feasibility of reclaiming wastewater for a variety of alternate uses, taking into account local restraints likely to be encountered.

Carnes et al. (5) presented an economic balance equation on reuse: Net cost = supply water cost + treatment for reuse cost + treatment for recovery cost - product recovery value. Comparative economics of a once-through system (either direct disposal or subsequent reuse) and a recycle system also were illustrated. Some generalizations made about the two systems were:

1. The feasibility of recycling with regards to cost depends on savings appreciated by handling a smaller volume of water as compared to the cost of treating the effluent for recycle.

2. Recycle systems are more judicious when contaminant additions are either low or easily removed and quality requirements are not stringent, e.g. cooling operations.

3. Product recovery is often only feasible in recycle systems.

4. Recycle systems become more attractive as final effluent requirements become more stringent.

5. Rigid feedwater quality requirements generally favor once-through systems.

Pingry (905) estimated functions, using regression techniques, which relate cost of energy use of wastewater treatment plants to measure of flow, treatment load and level of use. The sample of plants is drawn from Arizona and consists of plants which are or could be engaged in wastewater reuse. The resulting functions are used to estimate net water gain from reuse. In addition, bounds of value of water relative to energy which are necessary for reuse to be economical are calculated.

Brown (906) proposed an explanatory economic model for determination of water reuse rates based on the classical theory of the firm as a cost-minimizing institution. Water behavior of the firm is conceptualized as consisting of a finite set of interdependent relationships with each relationship representing some specific segment of the entire operation. Individual relations were constructed as jointly or simultaneously providing a theoretical representation of the entire ongoing manufacturing operation. Implementation of the theoretical model empirically requires very detailed information on cost structures of manufacturing water use, such as complete knowledge of the cost function of all potential levels of operation. With projections of how these functions will change over or with changing conditions in the economic environment of the firm, it would be possible to predict reuse rates utilizing the model.

Eckenfelder and Ford (907) qualitatively assessed the economic analyses that must be conducted when recycle operations are contemplated. The economics of various wastewater treatment methods were compared and analyzed. Among economic considerations discussed are returns to industry in terms of product recovery and water reuse. A generalized cost model for estimating capital costs of wastewater treatment facilities for different levels of renovation was included.

The optimized reuse of industrial wastewater can be accomplished economically by means of a mathematical model (646). Effects of variations in production process water, cost of effluent treatment, and cost and quality of reclaimed water were considered.

Eckenfelder and Barnard (908) detailed treatment cost relationships for industrial wastes. Economic analyses that must be conducted when recycle operations are contemplated were qualitatively assessed. Although recycling systems have often allowed product recovery not possible with singelpass systems, the latter were considered best suited to operations where process water quality requirements are inflexible.

Nelson (909) reported on methodology to economically evaluate potential power plant recycle/reuse systems. Eller, et al. (49) discussed an economic balance equation on water reuse and presented a simplified model establishing a basis for making economic decisions.

The usefulness of applying Kazanowski's cost-effectiveness approach to civil engineering systems is demonstrated by means of a case study of water reuse (910). The method facilitates evaluating and comparing alternative systems designed to reach a given goal. For each alternative system, the economic analysis, the environmental impact upon implementation, and the horizontal and vertical externalities are evaluated and presented in tabular form. The result of a sensitivity analysis performed on major system variables is given.

Water reuse operations, just as wastewater treatment to obtain a higher degree of effluent quality, will result in increased problems relating to disposal of solids and concentrated liquid sidestreams (826). Cost associated with such disposals must be included in the costs of producing water for reuse. To design the most cost-effective treatment system to attain the desired water quality, various processes must be analyzed as part of the total integrated system.

The ultimate costs to industry and to the economy of providing a degree of waste treatment sufficient to comply with statutory requirements will depend on the interweaving of a complex set of variables that includes, but is not limited to, industrial location, regulatory policy, rate of increase in industrial output, waste treatment technology, development of cooperative institutional arrangements, and the speed with which obsolete industrial plants are replaced (911).

It is impossible to consider multi-faceted water reuse operations on the basis of economic comparisons with typical fresh water (785). The costs of advanced treatment methods usually amount to several times the typical cost of normally purchased fresh water supplies. Truly valid comparisons can only be made when water pretreatment and waste processing costs are viewed together. Even then there are several factors on which a precise dollar value cannot be put, but which should be considered in the analysis. Situations such as decreasing supplies of fresh water, political and social implications regarding wastes, and changing quality requirements from both influent and effluent standpoints are all important when these factors are viewed. Collectively, it is sometimes found that onsite treatment and recovery of wastewaters is, in fact, the most technically practical and politically feasible course of action.

SECTION 6

DISCUSSION

While the panacea of zero effluent is to a large extent obviously not achievable in a complex chemical industry, a projection of present activity in both technical and pollution control enforcement directions will lead to a considerably increased degree of process water reclamation and reuse (575).

The limiting factors in implementing zero discharge appear to be the physical resources required, particularly for means to effect effluent volume reductions beyond those attainable by maximum recirculation and reuse of water within a plant (8). Energy requirements of evaporation, as well as capacity to produce such equipment, appear to be unrealistically high. Implementation of a strict definition of zero discharge of liquid effluents from industrial plants, utilizing technology clearly available, does not seem to be feasible in the near future.

The feasibility of successful reuse, involves matching the quality of renovated water with water quality requirements of each category of water use (19). A successful match eliminates water pollution and is equivalent to developing a new water supply. In some cases, the location and quantity of water available through reuse may be more attractive from both an engineering and economic viewpoint than transporting the same quantity of water from a natural source located outside the plant property line. It may be possible to directly match some high quality wastewater streams with a particular water use, thereby requiring no treatment. These cases represent the minimal amount of recycle that should be practiced assuming the wastewater is nearby and can be recycled practically.

In almost every industry recycle or reuse of water must be accomodated in the future for both economics and conservation (107). The increased expense of higher levels of wastewater treatment coupled with the projected future shortage of quality water may make reusable water the most valuable product recoverable from industrial wastewater (646).

A sound water management plant will reduce new water usage, thereby decreasing plant operating costs (26). Improved water management goes hand in hand with improved operations and product quality improvement.

Reuse possibilities are numerous and are often easy to propose (34). Each reuse case is different to some extent. The process engineer must be aware of reuse possibilities, significant problems that can occur, and experience available in solving similiar problems. If there is not sufficient confidence that the reuse possibility is indeed practical, some experimental work should be advisable--bench-scale, pilot-scale, or a limited test in the plant itself. In most cases some upgrading of wastewater will be needed to produce water of acceptable quality for reuse.

Reuse means eventually all dissolved or suspended materials must be accounted for (105). Those that cannot be thrown away, given away, or sold must be stored somewhere. Wastes that are necessary by-products will accumulate in quantities that cannot be further reduced by any waste control program. Removing water minimizes the volume of waste to be stored, but the cost of drying must be balanced against the reduced cost of storage. Waste can be converted to useful products only if the cost of conversion can be justified by the market value of the products. Careful segregation of waste streams can reduce cost of treatment and disposal substantially, and may permit profitable recovery of some of the toxic wastes.

The decision to recycle process water depends principally upon the quality of water required for the process and how seriously the water is affected by the process (912). In all cases the decision on what water can be recycled is not casual but is based on careful evaluations of processing requirements.

To make the most of effluent reuse, a total system approach which considers treatment of makeup, recycle, in-plant treatment, and effluent treatment must be pursued (309). If zero discharge is the objective, demineralization processes must be employed at one or more points within the overall scheme.

In developing plans for maximum water reuse, factors to be taken into account include the types of industries involved and the manufacturing processes employed, the age of industries located in the area, and other factors specific to major industrial categories (886). Factors which will determine the feasibility of water reuse include: 1) cost of water available to industry; 2) water quality standards or pretreatment requirements the industry will meet; 3) cost of treating water to a quality suitable for reuse; and 4) availability of land.

Attainment of the goal of complete water reuse will to a large degree eliminate water pollution problems and water shortages for the foreseeable future, and is worth expending a great deal of effort and resources (826). Achieving this goal will not be easy; however, efforts to attain it cannot be delayed. Fortunately, an impressive beginning toward achieving that goal has already been made.

There are many reasons to project an increase in the water reuse trend but certain pitfalls must be avoided (816). In sampling several hundred industrial wastewater facilities, some costly problems were uncovered. These stemmed mostly from improper design, poor operation, inadequate operator instruction, lack of maintenance, and absence of management interest. In many cases, corrective action could be taken, however, with careful design, training, personnel motivation, and other necessary factors, these problems should not arise in the first place, or should be easily minimized if they do arise. With good technology, proper motivation, and common sense, water cleanup goals can be achieved in a timely manner. Moreover, wastewater reuse will be a major step toward achieving these goals, and conserving a precious resource as well.

Wastewater reuse is clearly a necessity in our water economy. Many ways of accomplishing it have already been demonstrated. We cannot afford to do less than get the maximum amount of use out of our limited water supply.

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